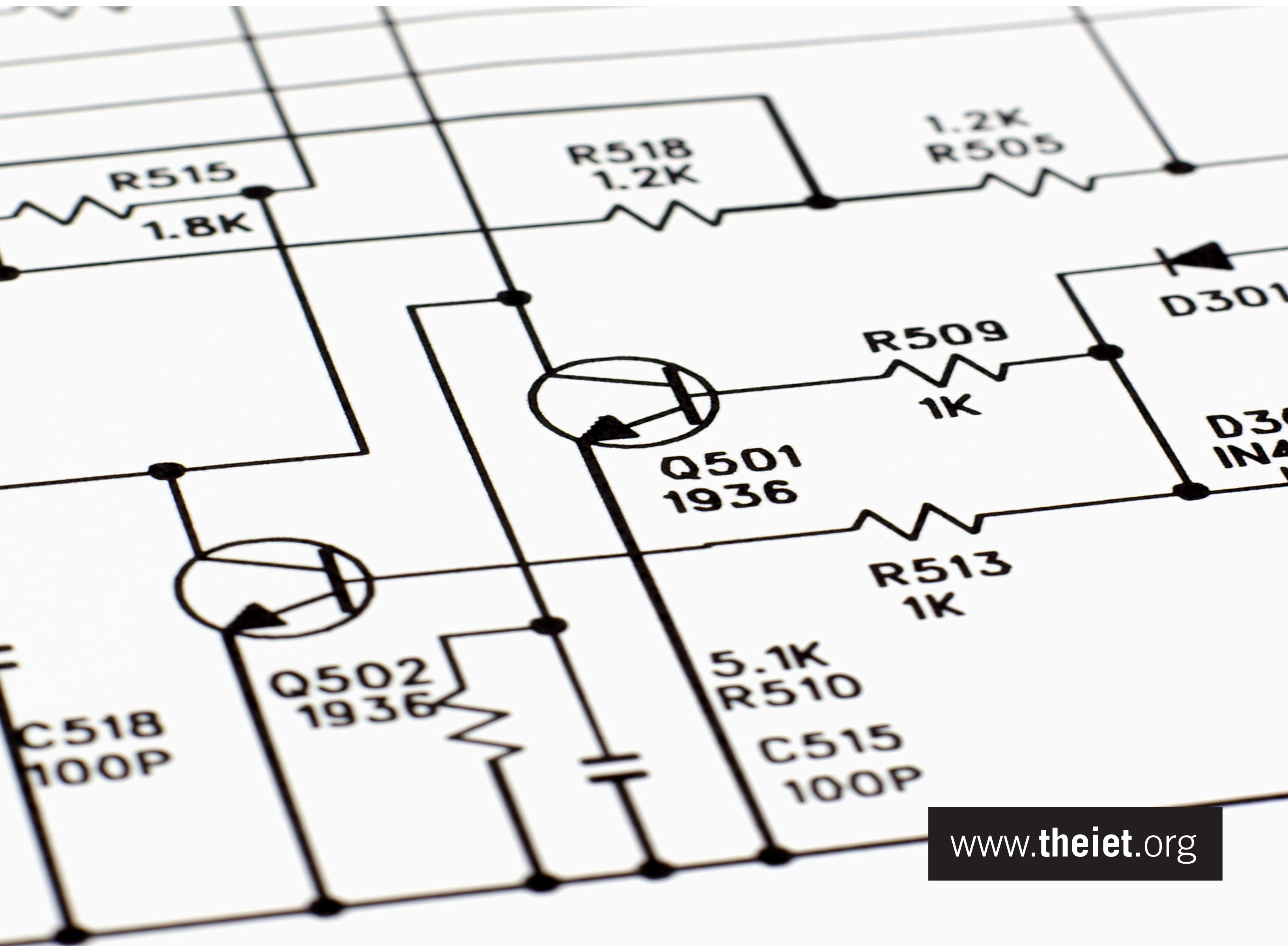
The Institution of Engineering and Technology

Units & Symbols
for Electrical & Electronic Engineers



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Preface

A booklet, Symbols and Abbreviations for use in Electrical and Electronic Engineering Courses, was published by the Institution of Electrical Engineers in 1968 and 1971. To take account of the many revisions and additions to British and International Standards since then, a new and fully revised edition was published in 1979, with reprints in 1980 and 1983.

In 1985, the editorial panel reconvened and undertook a total review and update of the Symbols and Abbreviations booklet, prior to it being re-issued under its new title in the professional brief series, in 1986. Further reviews of the contents were undertaken in 1991 and 1996. Any comments on the present content, or suggestions for additional material, will be welcomed. Please address comments to the Secretary of the Institution.

The booklet is for use by students and staff in colleges and universities, as a reference for authors of papers and books on electrical and electronic engineering and related subjects, and as a guide for draughtsmen and designers in industry.

Appendix A lists the standards which have been used in the preparation of this Guide.

Contents

Preface i

Introduction 1

Abbreviations for Words & Phrases 2

Printing Conventions 3
Letter symbols, subscripts 3

Unit Symbols 4
Compound symbols 4

Numerical Values 5
The decimal sign 5
Multiplication of numbers 5

The International System of Units 6
SI base units and supplementary units 6
SI derived units 7
Non-SI units 7

Quantity Symbols for Mechanics, Thermodynamics, Illumination 8

Quantity Symbols for Electrotechnics 10

Subscripts and other uses of Letters and Numbers 13
General 13
Semiconductors 15

Mathematical Symbols 16

Physical Constants 18

Conversion Factors 19
Length 19
Area, Volume 19
Mass, Density 19
Velocity 19
Force, Pressure, Torque 20
Energy, Power 20
Nucleonics, Radiation 20
Special remark on logarithmic quantities and units 21

Graphical Symbols 22
Connections and network elements 22
Power plant 23
Electronic devices 23
Logic symbols 24
Optic fibre symbols 25
Telecommunication symbols 26
Microwave devices 26
Flowchart symbols 27

Some Abbreviations 28
Commonly used abbreviations in optical, logic and microprocessor circuits 28
Component identification abbreviations 29

Letter and Digit Code for R & C Values 30

Appendix A **31**
Appendix B **32**
Appendix B **33**

Introduction

In the expression *I* = 16 mA, *I* is the quantity symbol for the physical phenomenon of electric current, and 16 is its numerical value in terms of the decimal submultiple (10^{-3}) of a unit (ampere) of current; mA is the unit symbol for milliampere. Other symbols (such as j, exp, Cu) are used to indicate mathematical operations, chemical elements etc. Frequently occurring technical phrases are commonly rendered as abbreviations (such as e.m.f., p.d.). In circuit diagrams, graphical symbols identify network components and devices.

International letter symbolism is based on the Roman and Greek alphabets. There are fewer than 90 distinctive capital and small letters to represent some thousands of scientific and technical quantities, and extensive duplication is unavoidable. Priority is given here to electrical, electronic and manufacturing engineering, and quantities in associated fields are, where necessary, assigned alternative or second-choice symbols.

The units and symbols listed throughout this booklet conform to the recommendations of the International Electrotechnical Commission (IEC) and the British Standards Institution (BSI). Additionally, because of their common usage, in the Logic Symbols under Section 12 some distinctive-shape binary logic symbols have been used.

1. Abbreviations for Words & Phrases

Well known abbreviations, such as those listed below, are set in small roman (lower-case upright) letters, except for proper names, the unit system (SI), at the start of a sentence (e.g. A.C., not A.c.), and in titles and table headings where preferred:

Alternating current*	a.c	Phase†	ph.
Direct current*	d.c.	Potential difference	p.d.
Electromotive force	e.m.f.	Power factor	p.f.
Per unit	p.u.	Root mean square	r.m.s.

*Adjective only, as in a.c. motor, d.c. circuit.
†As in 3-ph. Supply

Ad hoc abbreviations (such as s.s.b. for single sideband) may be employed subject to an initial use in context of the full expression. Some acronyms (e.g. radar, laser) are used as nouns. The use of capital letters without full points for some abbreviations is common, particularly in the fields of logic, computers and microprocessors (see *Commonly used abbreviations in optical, logical and microprocessor curcuits* in Section 13).

2. Printing Conventions

For clarity, in scientific and technical literature, different types of object are printed in different typefaces. The normal printing conventions are as follows:

Object	Typeface	Examples
unit symbols	Roman	Hz, s, μm
scalar physical quantities	Italic	*f*, *t*
vector physical quantities*	Italic boldface or Italic with arrow	***l*, *E*** $\vec{l}$, $\vec{E}$
numbers and numerical constants	Roman	17, π, e
numerical variables	Italic	x, x_n, $f(x)$
matrices	Italic boldface	***A***
standard mathematical functions	Roman	sin, $\log_e$

Note: the four styles of typeface are (using the letter A as an example):

Roman (or 'upright'):	A	Roman boldface:	**A**
Italic (or 'sloping'):	*A*	Italic boldface:	***A***

*this typeface also applies to phasor physical quantities

Letter symbols, subscripts

Letter symbols should be used with consistency (e.g. only *L* for self-inductance, only *P* for power), but distinguishing subscripts can be attached (e.g. L_1 and L_2). Upper-case letters (e.g. *V*, *I*) are used for steady, mean and r.m.s values; lower-case letters for instantaneous values which vary with time (e.g. *v*, *i*). Maximum, minimum and average are indicated by subscripts (e.g. V_{max}, V_{min}, V_{av}).

3. Unit Symbols

Unit symbols are printed in upright roman characters and are used after numerical values (e.g. 10 A, but ‘a few amperes’). They are the same in singular and plural, and are not followed by a full point except for normal punctuation, e.g. at the end of a sentence. A space is set between the number and its unit symbol (e.g. 230 V, not 230V). The decimal multiples and submultiples given below are prefixed, without a space, to the unit symbols (e.g. 6.6 kV). Compound decimal prefixes should not be used (e.g. pF, not μμF).

10^{24}	yotta	Y				10^{-3}	milli	m
10^{21}	zetta	Z				10^{-6}	micro	μ
10^{18}	exa	E	10^{2}	hecto	h	10^{-9}	nano	n
10^{15}	peta	P	10^{1}	deca	da	10^{-12}	pico	p
10^{12}	tera	T	10^{-1}	deci	d	10^{-15}	femto	f
10^{9}	gigi	G	10^{-2}	centi	c	10^{-18}	atto	a
10^{6}	mega	M				10^{-21}	zepto	z
10^{3}	kilo	k				10^{-24}	yocto	y

Powers in steps of 3 are preferred, but some others have common usage (e.g. centimetre cm, decibel dB).

Compound symbols

In a compound unit symbol, multiplication is denoted by either a dot or a space (e.g. N•m, N m). The last form may also be written without a space, provided that special care is taken when the symbol for one of the units is the same as the symbol for a prefix, e.g. mN means millinewton, not metre newton. Unit division may be indicated by a solidus (e.g. V/m). Not more than one solidus should appear in a combination (e.g. 5 m/s^2, not 5 m/s/s). In some cases parentheses or negative powers may be used for clarity (e.g. 1/s or s^{-1}; J/(m s K) or J m^{-1} s^{-1} K^{-1}).

4. Numerical Values

Numbers should generally be printed in roman (upright) type. To facilitate the reading of numbers with many digits, these may be separated into suitable groups, preferably of three digits, counting from the decimal sign towards the left and the right; the groups should be separated by a small space, and never by a comma or a point, nor by any other means.

The decimal sign

The IEC and the BSI indicate that a comma on the line is the preferred decimal sign. In most British Standards, most UK literature, and all USA literature it is the practice to use a dot on the line as the decimal marker. In order to avoid confusion the IET adopts the convention of English literature publications and uses a dot on the line as the decimal marker.

Multiplication of numbers

In the UK the preferred sign for the multiplication of numbers is a cross (X); if a dot is used as the decimal sign, the cross must be used. (A dot half-high may be used as the multiplication sign for numbers, but in this case a comma should be used as the decimal sign.)

5. The International System of Units

The International System of Units (SI) establishes three kinds of units: base, supplementary, and derived, discussed in the following sub-sections under Section 5. In addition, various other units, listed under the sub-heading Non-SI Units, are recognised for continued use alongside SI units. Many obsolescent non-SI units are listed in Section 11, where conversion factors are given.

SI base units and supplementary units

There are seven base units and two supplementary units, as shown below:

Base quantity	Name of SI base unit	Unit symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd
plane angle	radian	rad
solid angle	steradian	sr

The definitions of these units are as follows:

- **metre** (m): the metre is the length of the path travelled in vacuum by light during (1/299 792 458) second.
- **kilogram** (kg): the mass of the international prototype of the kilogram.
- **second** (s): the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium^{133} atom.
- **ampere** (A): that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2 x 10^{-7} newton per metre of length.
- **kelvin** (K): the unit of thermodynamic temperature is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water (but see footnote*).
- **candela** (cd): the luminous intensity, in a given direction, of a source which emits monochromatic radiation with a frequency 540 x 10^{l2} hertz and whose energy intensity in that direction is (1/683) watt per steradian.
- **mole** (mol): the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon^{12}. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.
- **radian** (rad): the plane angle between two radii of a circle which cut off on the circumference an arc equal in length to the radius.
- **steradian** (sr): the solid angle which, having its apex at the centre of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.

The supplementary units ‘radian’ and ‘steradian’ are to be regarded as dimensionless derived units which may be used or omitted in the expressions for derived units.

* In addition to the thermodynamic temperature (symbol T), expressed in kelvins, use is also made of Celsius temperature (symbol t) defined by the equation $t = T-T_o$ where $T_o = 273.15$ K by definition. The unit ‘degree Celsius’ is equal to the unit ‘kelvin’, but ‘degree Celsius’ is a special name in place of ‘kelvin’ for expressing Celsius temperature. A temperature interval or a Celsius temperature difference can be expressed in degrees Celsius as well as kelvins, but kelvin is to be preferred.

SI derived units

The units of all physical quantities are derived from the base and supplementary SI units, and certain of them have been named. These, together with some common compound units, are given here:

Quantity	Unit Name	Unit Symbol	Expression in terms of SI base unit
force	newton	N	m kg s^{-2}
energy	joule	J	m^2 kg s^{-2}
power	watt	W	m^2 kg s^{-3}
pressure, stress	pascal	Pa	m^{-1} kg s^{-2}
electric potential	volt	V	m^2 kg s^{-3} A^{-1}
electric charge	coulomb	C	s A
electric flux	coulomb	C	s A
magentic flux	weber	Wb	m^2 kg s^{-2} A^{-1}
magnetic flux density	tesla	T	kg s^{-2} A^{-1}
electric resistance	ohm	Ω	m^2 kg s^{-3} A^{-2}
electric conductance	siemens	S	m^{-2} kg^{-1} s^3 A^2
capacitance	farad	F	m^{-2} kg^{-1} s^4 A^2
inductance	henry	H	m^2 kg s^{-2} A^{-2}
Celsius temperature*	degree Celsius	oC	K
frequency	hertz	Hz	s^{-1}
luminous flux	lumen	Im	cd sr
activity (of a radionuclide)	becquerel	Bq	s^{-1}
absorbed dose	grey	Gy (=J/Kg)	m^2 s^{-2}
dose equivalent	sievert	Sv (=J/Kg)	m^2 s^{-2}
mass density	kilogram per cubic metre	kg/m^3	m^{-3} kg
moment of force	newton metre	N m	m^2 kg s^{-2}
torque	mewton metre	N m	m^2 kg s^{-2}
electric field strength	volt per metre	V/m	m kg s^{-3} A^{-1}
electrical displacement	coulomb per square metre	C/m^2	m^{-2} s A
magnetic field strength	ampere per metre	V/m	m^{-1} A
thermal conductivity	watt per metre kelvin	W m^{-1} K^{-1}	m kg s^{-3} K^{-1}
luminance	candala per square metre	cd/m^2	m^{-2} cd

*See footnote to previous sub-section - SI base units and supplementary units

Non-SI units

Some commonly used units not within the SI range are:

angle	degree ($1^\circ = \pi/180$ rad); minute ($1' = (1/60)^\circ$) second ($1'' = (1/60)'$); revolution (1 r = 2πrad)
energy	calorie (cal); electronvolt (eV); watt-hour (W h)
length	ångström (Å)
mass	ton (ton); tonne (= metric ton) (t) unified atomic mass unit (u)
pressure, stress	atmosphere (atm); bar (bar); torr (Torr)
rotational frequency	revolution per minute (r/min)*, revolution per second (r/s)*
time	minute (min); hour (h); day (d); year (a)
volume	litre (L, l or litre)

*These are widely used for rotational frequency in specifications of rotating machinery.

6. Quantity Symbols for Mechanics, Thermodynamics, Illumination

As noted in Section 2, an italic typeface is used for quantity symbols.

Quantity	Symbol	SI Unit
acceleration, angular	α	rad/s^2
acceleration, linear	a	m/s^2
acoustic pressure	ρ	Pa
angle, plane	α, β, γ	rad
angle, solid	Ω	sr
angular momentum	L	$kg\ m^2\ s^{-1}$
area, surface area	A, S	m^2
bulk compressibility	K	m^2/N
coefficient of heat transfer	α	$W\ m^{-2}\ K^{-1}$
density	ρ	kg/m^3
efficiency	η	-
energy	E	J
energy, kinetic	E_k	J
energy, potential	E_p	J
energy, volume density	W	J/m^3
enthalpy	$H\ (=U=pV)$	J
entropy	S	J/K
force	F	N
frequency	f	Hz
frequency, angular	ϖ	rad/s
friction, coefficient	μ	-
friction, force coefficient	F	N s/m
friction, torque coefficient	F	N m s/rad
Gibbs function	$G\ (=U+pV-TS)$	J
heat, quantity of heat	Q	J
heat, heat capacity	C	J/K
heat, specific heat capacity	c	$J\ kg^{-1}\ K^{-1}$
heat, flow rate	φ_{th}	W
heat, density of heat flow rate	q	W/m^2
Helmholtz free energy	$A, F\ (A=U-TS)$	J
illumunance	E	Lx
internal energy	U	J
isentropic exponent	$K \left(= -\frac{V}{p}\left(\frac{\partial p}{\partial V}\right)_s\right)$	-
kinematic viscosity	v	m^2/s
length	l	m
luminance	L	cd/m^2
luminous flux	φ	lm
luminous intensity	l	cd
mass	m	kg
mass flow rate	q_m	kg/s
mechanical impedance	Z_m	N s/m
moduli, modulus of elasticity (Young)	E	Pa
moduli, longitudinal modulus of elasticity	E	N/m^2
moduli, sheer modulus, modulus of rigidity	G	N/m^2
moduli, bulk modulus, modulus of compression	K	N/m^2
moment of force	M	N m
moment of inertia	J	$kg\ m^2$

6. Quantity Symbols for Mechanics, Thermodynamics, Illumination (continued)

Quantity	Symbol	SI Unit
momentum	p	kg m/s
Poisson ratio	μ	-
pressure, stress	p	Pa
radius of gyration	k	m
ratio of specific heat capacities	$Y (=c_p/c_v)$	-
second axial moment of force	l_a	m^4
second polar moment of area	l_p	m^4
specific heat capacity, constant pressure	c_p	-
specific heat capacity, constant volume	c_v	-
specific heat capacity, staturation	c_{sat}	-
strain, linear	ε	-
strain, sheer	Y	-
strain, volume strain, bulk strain	Θ	-
surface tension	Y	N/m
temperature, thermodynamic temperature	T, Θ	K
temperature, Celsius temperature	t,	ºC
temperature interval	-	K
thermal, conductivity	λ, k	$w\ m^{-1}\ K^{-1}$
thermal, resistance	R_{th}	K/W
time	t	s
time constant	τ	s
torque	T	N m
velocity, angular	ω	rad/s
velocity, linear	v	m/s
viscosity	η	Pa s
viscosity, kimematic		m^2/s
volume	V	m^3
volume, specific	v	m^3/kg
volume, flow rate	g_v	m^3/s
weight	G	N
work	W	j

7. Quantity Symbols for Electrotechnics

Quantity	Symbol	SI Unit
admittance	Y	S
attenuation	A	Np† dB†
attenuation coefficient	α	m^{-1}
bandwidth	B	Hz
capacitance	C	F
charge	Q	C
charge density, surface	σ	C/m^2
charge density, volume	ρ	C/m^3
conductance	G	S
conductance, mutual	g_m	S
conductivity	Y, σ	S/m
control angle, rectifier	α	rad
control angle, inverter	β	rad
coupling factor	k	-
current	I	A
current density, area	J	A/m^2
current density, linear	A	A/m
current linkage	Θ	A
damping coefficient	δ	s^{-1} (or Np/s)
decrement, logarithmic	λ	-
dipole moment, electric	p	C m
dipole moment, magnetic	j	Wb m
dissipation factor	d	-
distortion factor	d	-
electric constant	ε_o	F/m
electric field, strength	E	V/m
electric field, level	L_e	Np††
electric flux	Ψ	C
electric flux density	D	C/m^2
electric polarisation	P	C/m^2
electric susceptibility	χ, χ_ε	-
electromotive force	E	V
energy	E, W_e	J
energy, Fermi	ε	J‡
feedback factor	β	-
frequency	f	Hz
frequency, angular	ω	rad/s
frequency, deviation	Δf	Hz
frequency, complex angular	p	s^{-1}
gain	G	-
group velocity	c_g, v_g	m/s
group delay	t_g	s
Hall coefficient	R_h, A_h	m^3/C
impedance	Z	Ω
impedance, characteristic	Z_o	Ω
impedance, surge	Z_o	Ω
inductance, self	L	H
inductance, mutual	L_{jk}, M	H
leakage factor	σ	-

† Not a SI unit but in common use—also see section 11 sub section **Special remark on Logarithmic quantities and units**
†† Not a SI unit but in common use
‡ More usually expressed in eV

7. Quantity Symbols for Electrotechnics (continued)

Quantity	Symbol	SI Unit
loss angle	δ	rad
magnetic constant	μ_o	H/m
magnetic field strength	H	A/m
magnetic flux	Φ	Wb
magnetic flux density	B	T
magnetic flux linkage	Ψ	Wb
magnetic (area) moment	m	A m^2
magnetic polarisation	B_i J	T
magnetic susceptibility	χ, κ	-
magnetic vector potential	A	Wb/m
magnetisation	H_i M	A/m
magnetomotive force	F, f_m	A
mobility	μ	m^2 V^{-1} s^{-1}
modulation factor (a.m.)	m	-
modulation factor (f.m.)	δ	rad
noise factor	F, F_n	-
noise power	P_n	W
noise temperature	T_n	K
number density of particles	n	m^{-3}
number of phases	m	-
number of pole pairs, pulses	p	-
number of turns	N	-
period	T	s
permeability, absolute	μ	H/m
permeability, relative	μ_r	-
permeance	Λ	H, Wb/A
permittivity, absolute	ε	F/m
permittivity, relative	ε_r	-
phase, angle	Φ	rad
phase, delay	t_o	rad
phase, deviation	$\Delta\Phi$	rad
phase change	B	rad
phase-change coefficient	β	rad/m
phase velocity	c_Φ, v_Φ	m/s
polarisation, electric	P	C/m^2
polarisation, magnetic	B_i, J	T
potential	V	V
potential difference	U, V	V
power, active	P	W
power, apparent	S	V A
power, reactive	Q	var†
power factor	λ	-
power factor, sinusoidal	cos Φ	-
power-level difference	-	Np†, dB†
Poynting vector	S	W/m^2
propagation coefficient	γ	m^{-1}
Q (quality) factor	Q	-
radiant energy	Q, W	J
radiation resistance	R_r	Ω

† Not a SI unit but in common use

7. Quantity Symbols for Electrotechnics (continued)

Quantity	Symbol	SI Unit
rating	S	V A, W
reactance	X	Ω
reflection coefficient	r, p	-
refractive index	n	-
regulation	ε	p.u.†
reluctance	R, R_m	H^{-1}, A/Wb
resistance	R	Ω
resistance-temperature coefficient	α	K^{-1}
resistivity	ρ	Ω m
signal	S	-
slip	s	-
standing-wave radio	s	-
susceptance	B	S
susceptibility, electric	χ, χ_ε	-
susceptibility, magnetic	χ, κ	-
transconductance	g_m	A/V, S
transfer function	H	-
transmission factor	τ	-
turn-on, turn-off time	t_{on}, t_{off}	s
voltage	U, V	V
wavelength	λ	m
work function	Φ	J ‡

† Not a SI unit but in common use
‡ More usually expressed in eV

8. Subscripts and other uses of Letters and Numbers

It is recommended as a guiding principle for the printing of subscripts that, when these are symbols for physical quantities, they should be printed in italic type. Numbers as subscripts should be printed in roman type; mathematical variables (e.g. running subscripts) should be printed in italic type. All other subscripts should be printed in roman type.

Some commonly used abbreviations, often occurring as subscripts, are as follows:

General

a	absolute	**exp**	experimental
	acoustic		
	active	**f**	field
	additional		filament, heater
	alternating		final
	ambient		forward
	anode		frequency
	anti-resonance	**fl**	floating
	axial		
amb	ambient	**g**	airgap
as	asynchronous		gate
av	average		grid
			group
b	backward		
	base	**h**	hysteresis
br	breakdown		height, depth
			hybrid
c	calculated		
	carrier	**i**	ideal
	case		image
	coercive		induced
	collector		initial
	correction		input
	critical		instantaneous
	cut-off		intermediate
ch	chemical		internal
cp	composite		intrinsic
cr	critical	**im**	image
		in	insertion
d	d-axis	**ind**	indirect
	damped		
	delay	**j**	junction
	deviation		
	diameter	**k**	cathode
	difference		knee
	diffuse		iterative
	direct		short circuit
	dissipation	**K**	transformation ratio
	distortion		
	dynamic	**l**	leakage
dem	demodulation		limiting
			line
e	effective		local
	electric		longitudinal
	emitter	**L**	load
	equivalent		large signal
	error		
	external		

8. Subscripts and other uses of Letters and Numbers (continued)

m	magnetic	**r (cont)**	resonance
	magnetising		resulting
	maximum		reverse
	measured		reverse transfer
	mechanical		rotational
	mutual		rotor
	peak value	**ref**	reference
max	maximum	**rms**	root mean square value
med	median		
min	mimimum	**s**	secondary
mod	modulation		segment
			series
n	natural		signal
	noise		spherical
	nominal		standardised
			static
o	output		stator
	spherical characteristic in vacuo		steady issue
oc	open circuit		storage
opt	optical		synchronous
or	original	**sat**	saturation
ov	overload	**sc**	short-circuit
		sim	simultaneous
p	parallel, shunt	**sin**	sinusodial
	parasitic	**stg**	storage
	pole, or pairs of poles	**suc**	successive
	primary		
	psophometric	**t**	tangential
	pulse		total
pd	pull down		transient
ph	phase		transmission
pk	peak		transverse
pt	punch through	**th**	thermal
pu	pull up		theoretical
p-p	peak-to-peak	**tot**	total
q	q-axis	**u**	usual
	quadrature		useful
	quiescent		
	turn off	**v**	luminous
			vartying
r	radical		vacuum
	radiation		valley
	rated		
	real	**wdg**	winding
	relative		
	reflection	**x**	reactive
	remanent		crosstalk
	residual		

8. Subscripts and other uses of Letters and Numbers (continued)

0	characteristic free space no load zero frequency	**2**	negative sequence output port 2 second harmonic secondary
1	full load fundamental input port 1 positive sequence primary	**3**	tertiary
		$\|$, p	parallel
		$\perp$, n	perpendicular
		0, s	spherical
		∞	at infinity

Semiconductors

To the incremental hybrid (*h*), admittance (*y*) and impedance (*z*) parameters, double subscripts are applied in the order (1) function, (2) common electrode:

(1) i or 11 input; o or 22 output; f or 21 forward transfer; r or 12 reverse transfer.
(2) b base; c collector; d drain; e emitter; g gate; s source (e.g. h_{oe}, y_{12b}).

The upper-case variant of the subscript is used for static (d.c.) or large-signal values (e.g. h_{FE}, h_{21F}).

The real and imaginary parts of a device impedance are shown, respectively, by Re and j Im (e.g. h_{ie} = Re (h_{ie}) + j Im (h_{ie})).

Upper-case letters are used for the representation of electrical parameters of external circuits and all inductances and capacitances. Except for *L* and *C*, lower-case letters are used for electrical parameters inherent in the device (e.g. r_e). In equivalent circuits using 3-terminal devices, a third letter may be used to indicate the condition at the third terminal (e.g. V_{CBO} where $I_E = 0$), while the first subscript indicates one terminal of the device and the second subscript the reference terminal or circuit node.

9. Mathematical Symbols

Term	Symbol
$\sqrt{-1}$	j
ratio of circumference to diameter of circle	$\pi (\approx 3.141\ 592\ 654)$
base of natural logarithms	e ($\approx$2.718 281 828)
exponential function (to the base e) of *x*	e^x, exp *x*
logarithm to the base *a* of *x*	$\log_a x$
natural logarithm of *x*	$\ln x$ ($\equiv \log_e x$)
common logarithm of *x*	$\lg x$ ($\equiv \log_{10} x$)
binary logarithm of *x*	lb x ($\equiv \log_2 x$)
circular functions of *x*	sin *x*, cos *x*, tan *x*
inverse circular functions of *x*	arcsin *x*, arccos *x*, arctan *x*
hyperbolic functions of *x*	sinh *x*, cosh *x*, tanh *x*
inverse hyperbolic functions of *x*	arsinh *x*, arcosh *x*, artanh *x*
sum	$\sum$
product	Π
function *f*	*f*
value of the function *f* at *x*	*f*(x)
limit to which *f*(*x*) tends as *x* approaches *a*	$\lim_{x \to a} f(x)$
finite increment of *x*	Δx
variation of *x*	∂f
total differential of *f*	d*f*
operators $\frac{\partial}{\partial x}$, $\frac{d}{dx}$	D_x, D
differential coefficient of order *n* of *f*(*x*)	$\frac{d^n f}{dx^n}$, $f^{(n)}(x)$
partial differential coefficient of order *f* (*x*, *y*, ...) with respect to *x*, when *y*, ... are held constant	$\frac{\partial f}{\partial x}$ (x, y,...), $\left(\frac{\partial f}{\partial x}\right)_{y,...}$
indefinite integral of *f*(*x*) with respect to *x*	$\int f(x)dx$
definitive integral of *f*(*x*) from *x* = *a* to *x* = *b*	$\int_a^b f(x)dx$
convolution product of *f* and *x*	$f*g$
matrix ***A***	$\begin{pmatrix} A_{11} & \cdots & A_{1n} \\ \vdots & & \vdots \\ A_{m1} & \cdots & A_{mn} \end{pmatrix}$
inverse of the square matrix ***A***	A^{-1}
transpose matrix of ***A***	A^T, $\tilde{A}$
complex conjugate matrix of ***A***	A^*
determinant of the square matrix ***A***	*det* ***A***, $\begin{vmatrix} A_{n} & \cdots & A_{ln} \\ \vdots & & \vdots \\ A_{nl} & \cdots & A_{nn} \end{vmatrix}$

9. Mathematical Symbols (continued)

Term	Symbol
vector ***A***	$\vec{\boldsymbol{A}}$, (A also used)
magnitude of the vector ***A***	A, $\lvert\mathbf{A}\rvert$
scalar product of ***A*** and ***B***	$\mathbf{A} \bullet \mathbf{B}$
vector product of ***A*** and ***B***	$\boldsymbol{A}\ \boldsymbol{x}\ \boldsymbol{B}$
del operator	∇
gradient of ø	∇ø, grad ø
divergence of ***A***	$\nabla \bullet \boldsymbol{A}$, div $\boldsymbol{A}$
curl of ***A***	∇ x $\boldsymbol{A}$, curl $\boldsymbol{A}$
Laplacian	$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$
D'Alembertian	$\square = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} - \frac{1}{c^2} \cdot \frac{\partial^2}{\partial t^2}$

10. Physical Constants

Quantity	Symbol	Numerical Value	Unit
acceleration of free fall (standard)	g_n	9.806 65*	m/s^2
atmospheric pressure (standard)	p_o	$1.013\ 25 \times 10^5$*	Pa
atomic mass constant (unified)	m_u	$1.660\ 540 \times 10^{-27}$	kg
Avogadro constant	N_A	$6.022\ 137 \times 10^{23}$	mol^{-1}
Bohr magneton	μ_B	$9.274\ 015 \times 10^{-24}$	J/T
Boltzmann constant	k	$1.380\ 658 \times 10^{-23}$	J/K
elementary (proton) charge	e	$1.602\ 177 \times 10^{-19}$	C
electron: charge	-e	$-1.602\ 177 \times 10^{-19}$	C
electron: rest mass	m_e	$9.109\ 390 \times 10^{-31}$	kg
electron: charge/mass ratio	e/m_e	$1.758\ 820 \times 10^{11}$	C/kg
Faraday constant	F	$9.648\ 531 \times 10^4$	C/mol
free space: electric constant	ε_o	$8.854\ 188 \times 10^{-12}$	F/m
free space: intrinsic impedance	Z_o	376.730 3	Ω
free space: magnetic constant	μ_o	$4\pi \times 10^{-7}$	H/m
free space: speed of e.m. waves	c	$2.997\ 924\ 58 \times 10^8$*	m/s
gravitational constant	G	$6.672\ 59 \times 10^{-11}$	$N\ m^2\ kg^{-2}$
ideal molar gas constant	R	8.314 510	$J\ mol^{-1}\ K^{-1}$
neutron rest mass	m_n	$1.674\ 929 \times 10^{-27}$	kg
Planck constant	h	$6.626\ 076 \times 10^{-34}$	J s
normalised (h/2π)	$\hbar$	$1.054\ 573 \times 10^{-34}$	J s
proton: charge	$+e$	$1.602\ 177 \times 10^{-19}$	C
proton: rest mass	m_p	$1.672\ 623 \times 10^{-27}$	kg
proton: charge/mass ratio	e/m_p	$9.578\ 831 \times 10^7$	C/kg
radiation constants	c_1	$3.741\ 775 \times 10^{-16}$	$W\ m^2$
	c_2	$1.438\ 769 \times 10^{-2}$	m K
Stefan-Boltzmann constant	σ	$5.670\ 51 \times 10^{-8}$	$W\ m^{-2}\ K^{-4}$
unified atomic mass unit (is one twelfth of the mass of the atom of the nuclide 12C)		$1.660\ 540 \times 10^{-27}$	kg
velocity of sound in air (s.t.p.)	c	331.45	m/s

* exact values

Values of physical constants (apart from speed of sound) derived from CODATA Bulletin No. 63, Nov. 1986.

11. Conversion Factors

Exact values are shown with an asterisk *.
Some of these units may no longer have a legal validity.

Length

1 Å	100.0*	pm
1 mil	25.4*	μm
1 in	25.4*	mm
1 ft	0.304 8*	m
1 yd	0.914 4*	m
1 mile	1.609 344*	km
1 nautical mile	1.852*	km
1 astronomical unit	0.149 597 87*	Tm
1 light year	9.460 3	Pm

Area, Volume

1 in^2	645.16*	mm^2
1 ft^2	0.092 903 04*	m^2
1 yd^2	0.836 127	m^2
1 ha	10 000.0*	m^2
1 in^3	16 387.064*	mm^3
1 litre	1.0*	dm^3
1 UK fluid ounce	28.41×10^{-6}	m^3
1 UK gal	4.546 09	L
1 US gal	3.785 41	L
1 ft^3	0.028 316 8	m^3
1 yd^3	0.764 555	m^3
1 $mile^2$ (640 acres)	2.589 98	km^2
1 are	100.0*	m^2
1 acre (4840 yd^2)	4 046.855	m^2

Mass, Density

1 oz (adp)	28.35	g
1 oz (troy)	31.10	g
1 lb	0.453 592.37*	kg
1 tonne	1 000.0*	kg
1 (UK) ton	1 016.05	kg
1 lb/ft^3	16.018 5	kg/m^3
1 lb/in^3	27.68	Mg/m^3
1 cwt (UK)	50.802 3	kg
1 carat	0.2*	g

Velocity

1 ft/s	0.304 8*	m/s
1 mile/h	0.447 04*	m/s
1 knot	0.514 4	m/s

Force, Pressure, Torque

1 ozf	278.0	mN
1 lbf	4.448 22	N
1 kgf	9.806 65*	N
1 Torr	133.322	Pa
1 mm Hg	133.322	Pa
1 in H_2O	249.09	Pa
1 m H_2O	9.806 65*	kPa
1 bar	100.0*	kPa
1 lbf/in^2	6.894 76	kPa
1 ft lbf	1.355 82	N m
1 dyne	10.0*	μN
1 standard atmosphere	0.101 325*	MPa

Energy, Power

1 eV	0.160 218 2	aJ
1 cal (international table)	4.186 8*	J
1 Cal (= 1 kcal thermochemical)†	4.184*	kJ
1 ft lbf	1.355 82	J
1 m kgf	9.806 65*	J
1 Btu	1.055 06	kJ
1 therm	105.506	MJ
1 kW h	3.6*	Mj
1 ft lbf/s	1.355 82	W
1 m kgf/s	9.806 65*	W
1 Btu/h	0.293 071	W
1 hp (UK)	0.745 7	kW
1 erg/s	0.1*	μW

† Widely used for energy content of food. (There are different 'calories', of marginally different sizes; also note that the 'big calorie', used in newspapers etc., is 1000 times the corresponding 'small calorie'.)

Nucleonics, Radiation

Curie	1 Ci	3.70×10^{10}*	Bq
rad	1 rd	0.01*	Gy
Röntgen	1 R	2.58×10^{-4}*	C/kg
barn	1 barn (or 1 b)	10^{-28}*	m^2
foot-candle	1 ft cd	10.76	lx

Special remark on logarithmic quantities and units

The expression for the time dependence of a damped harmonic oscillation can be written either in real notation or as the real part of a complex notation

$F(t) = A\, e^{-\partial t} \cos(\omega t) = \mathrm{Re}(A\, e^{-(\partial + j\omega)t})$

This simple relation involving ∂ and ω can be obtained only when e (base of natural logarithms) is used as the base of the exponential function. The coherent SI unit for the damping coefficient ∂ and the angular frequency ω is second to the power minus one, i.e. 1/s. Using the special names neper, Np, and radian, rad, for the units of ∂t and ωt respectively, the units for ∂ and ω become neper per second, Np/s, and radian per second, rad/s, respectively. Neper and radian are special names for the 'dimensionless' unit one, 1. The neper is used as a unit for logarithmic quantities; the radian is used as a unit for plane angles and for the phase of circular functions.

Corresponding variation in space is treated in the same manner

$F(x) = A\, e^{-\alpha x} \cos(\beta x) = \mathrm{Re}(A\, e^{-\gamma x}),\ \gamma = \alpha + j\beta$

where the unit for α is neper per metre, Np/m, and the unit for β is radian per metre, rad/m.

In ISO 31, the level of a field quantity is therefore defined as the natural logarithm of a ratio of two amplitudes, $L_F = \ln(F/F_0)$, and is hence a quantity of dimension one. The unit neper (= the number 1) is the level of a field quantity when $F/F_0 = e$.

Since power is often proportional to the square of an amplitude, a factor 1/2 is introduced in the definition of the level of a power quantity $L_p = (1/2) \ln(P/P_0)$ in order to make the level of the power quantity under these circumstances equal to the level of the field quantity.

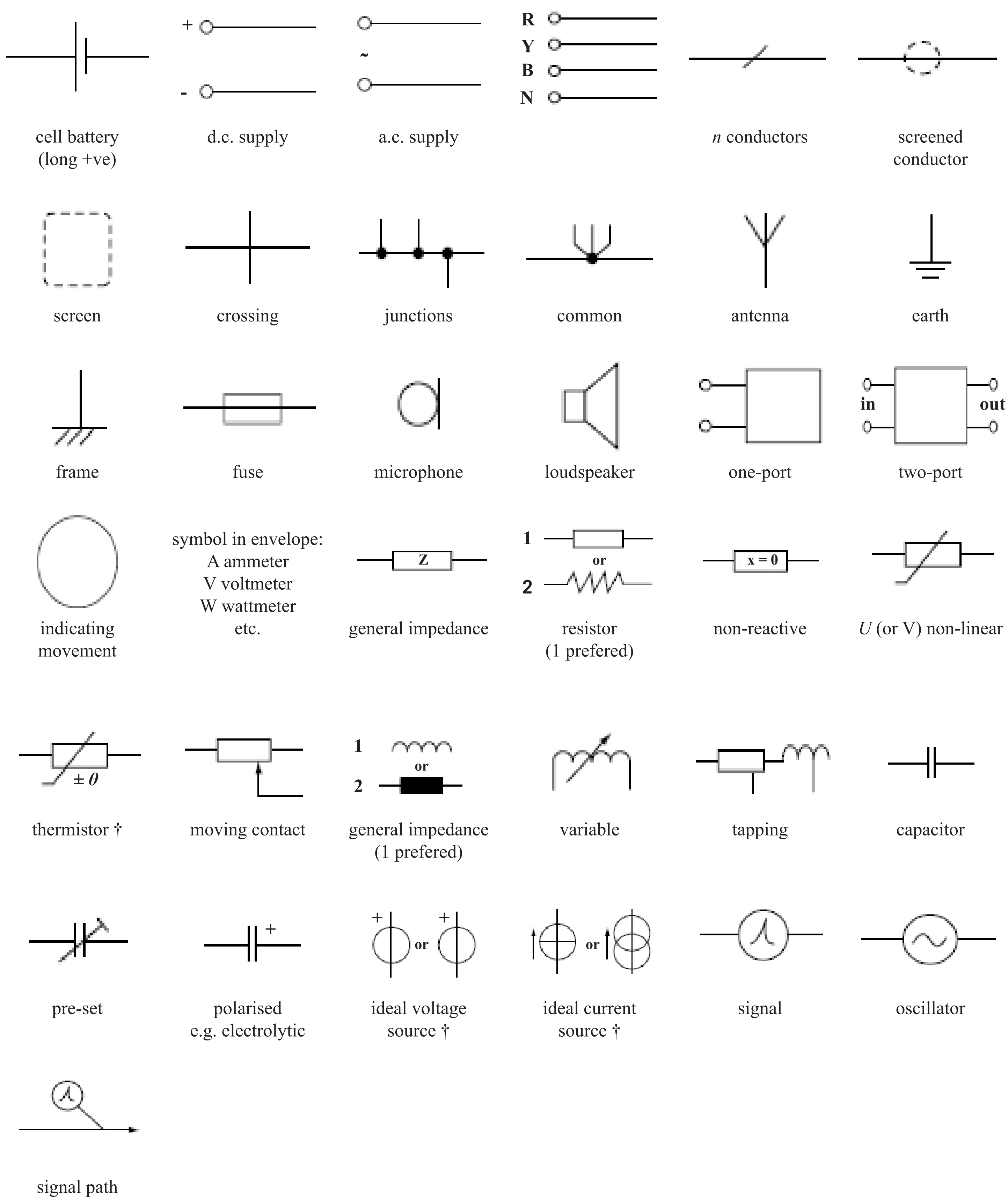
In practice the non-coherent unit degree, …°, ($1° = \pi/180$ rad) is often used for angles and the non-coherent unit bel, B, [1 B = (1/2) $\log_e^{10}$ Np ≈ 1.151 293 Np] is based on common logarithms (base 10) for logarithmic quantities. Instead of the bel, its sub-multiple the decibel, dB, is commonly used.

Some numerical conversion factors are:

power level	1 dB	0.05 $\log_e$ 10 Np (=0.115 129 Np)
	1 Np	20 $\log_{10}$ e dB (≈8.686 dB
frequency	1 octave	$\log_{10}$ 2 decade (≈0.301 decade)
	1 decade	$\log_2$ 10 octave (≈3.321 octave)

12. Graphical Symbols

Connections and network elements



† Not in BS but in common use

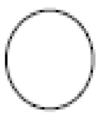
Power plant

Transformers:

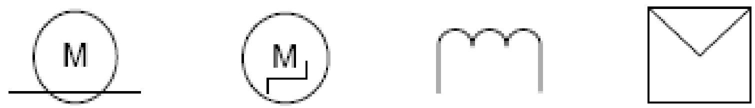
2-wdg | 3-wdg | auto | current or pulse

if desired, core shown by single line annotated to indicate material

Machines:



descriptive symbols in envelope:
G (generator), M (motor), G d.c., M a.c.
S (synchronous), GS, MS



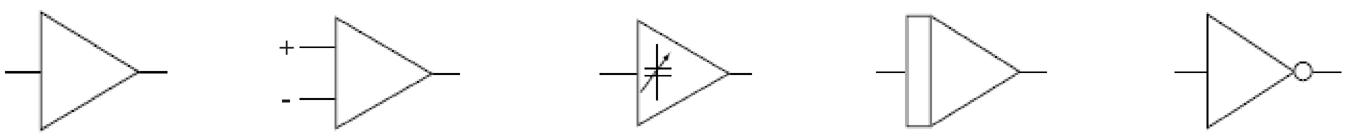
linear M | stepping M | wdgs | M starter

choke reactor | circuit-breaker | isolator | gap | bridge rectifier | converter

{ -/ d.c.
~/ rectifier
-/ inverter
etc.

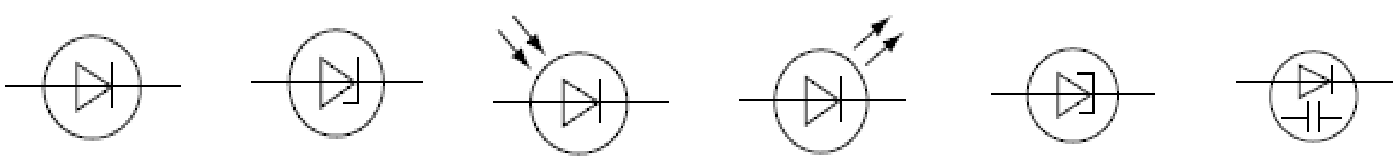
Electronic devices

Amplifiers:



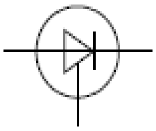
general | operational | parametric | integrating | inverting

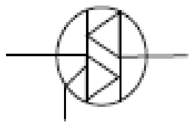
Diodes:

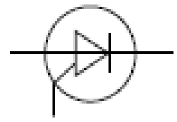


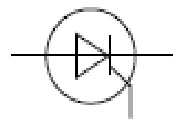
general | breakdown diode, Esaki diode | photo-diode | light emitting diode | tunnel diode | varactor

Thyristors:


triode thyristor
(type unspecified)


triac


reverse blocking n-gate


triode thyristor p-gate

Cells:

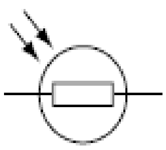


photo-conductive device

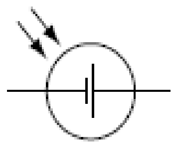
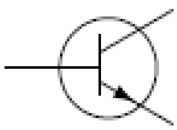
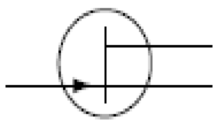


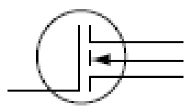
photo-voltaic

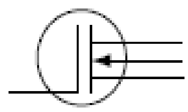
Transistors:

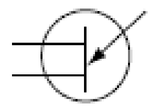
(for p-type arrows
are reversed)


npn transistor


JUGFET
n-channel

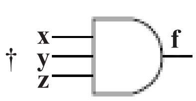

IGFET †
n-channel
enhancement

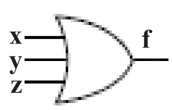

IGFET †
n-channel
depletion

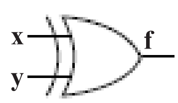

unijunction
transistor with
n-type base

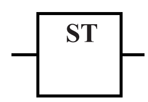
(use of the envelope symbol is optional unless there is a connection to it)
† with substrate connection brought out

Logic symbols

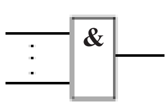




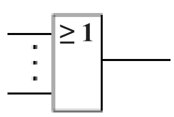




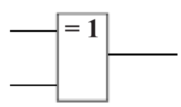
BS 3939 (1991)



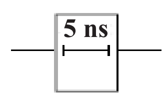
AND element



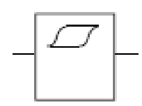
Or element



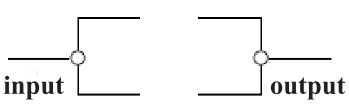
EX CL OR



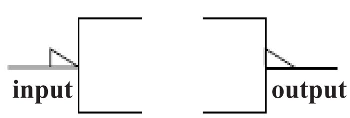
delay element
(5 ns)


Schmitt trigger

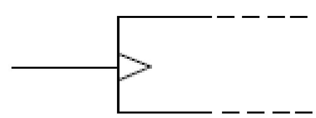
† Not in BS but in common use



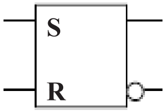
logic negation



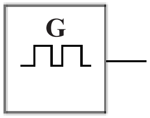
logic polarity


dynamic input

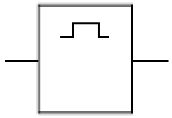
Logic symbols (continued)



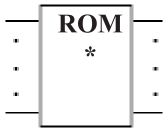
RS-bistable



astable element

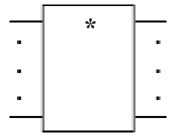


monostable



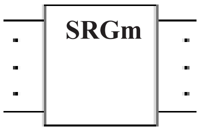
memories: ROM; PROM; RAM; CAM

asterisk: indicates no. of addresses and bits

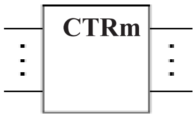


arithmetic elements

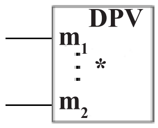
asterisk:
∑ adder
P-Q subtractor
π multiplier
ALU arithmetic logic unit



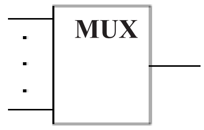
shift register



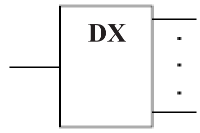
counter



display unit

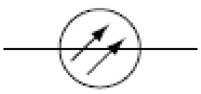


multiplexer

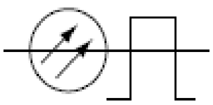


demultiplexer

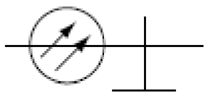
Optic fibre symbols



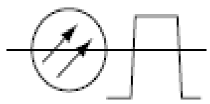
optical fibre
optical fibre cable



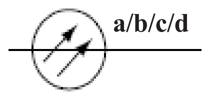
multimode stepped index optical fibre



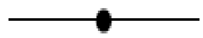
single mode stepped index optical fibre



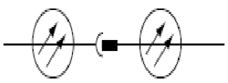
graded index optical fibre



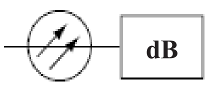
a core diameter
b cladding "
c first coating "
d jacketing "



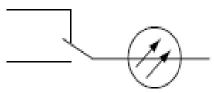
permanent joint



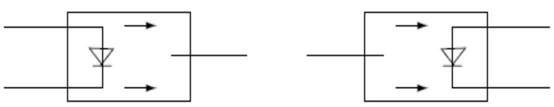
optical connection female-male



optical attenuator

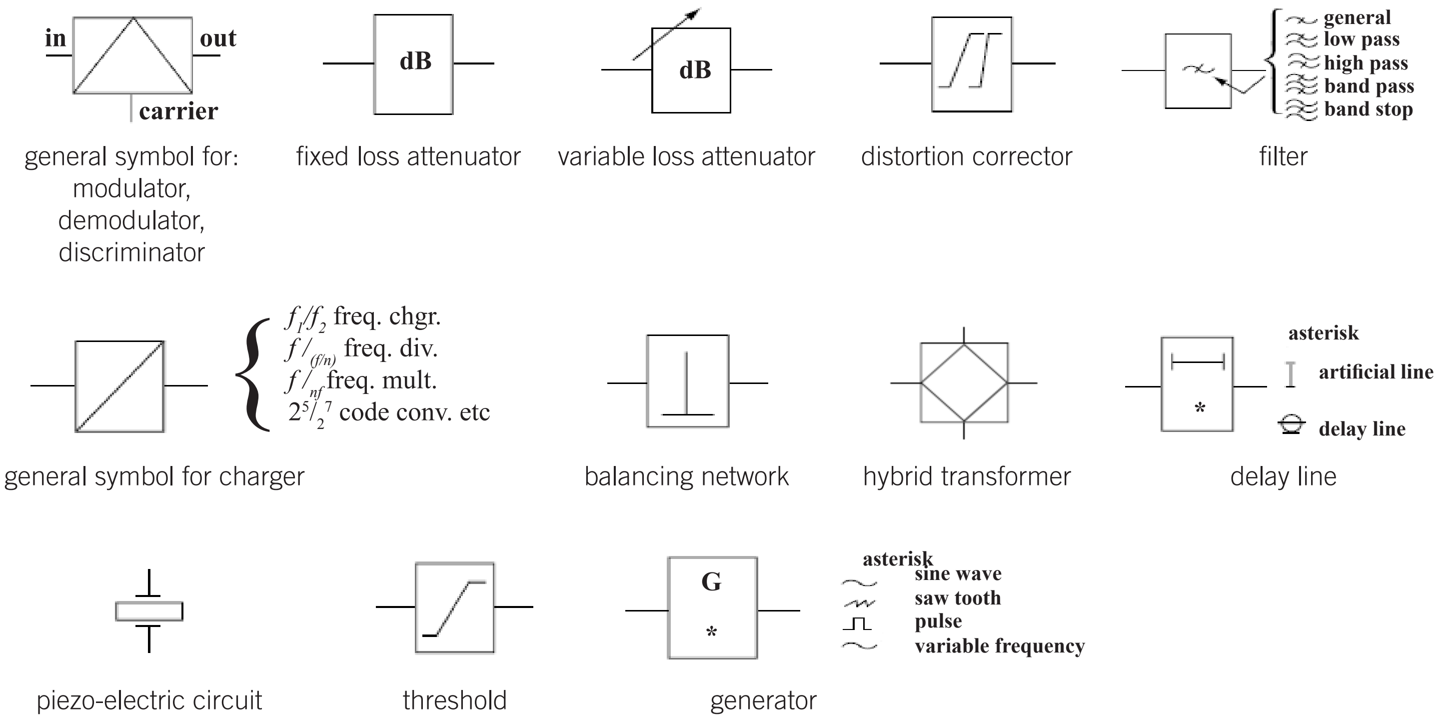


changeover contact in optical fibre circuit

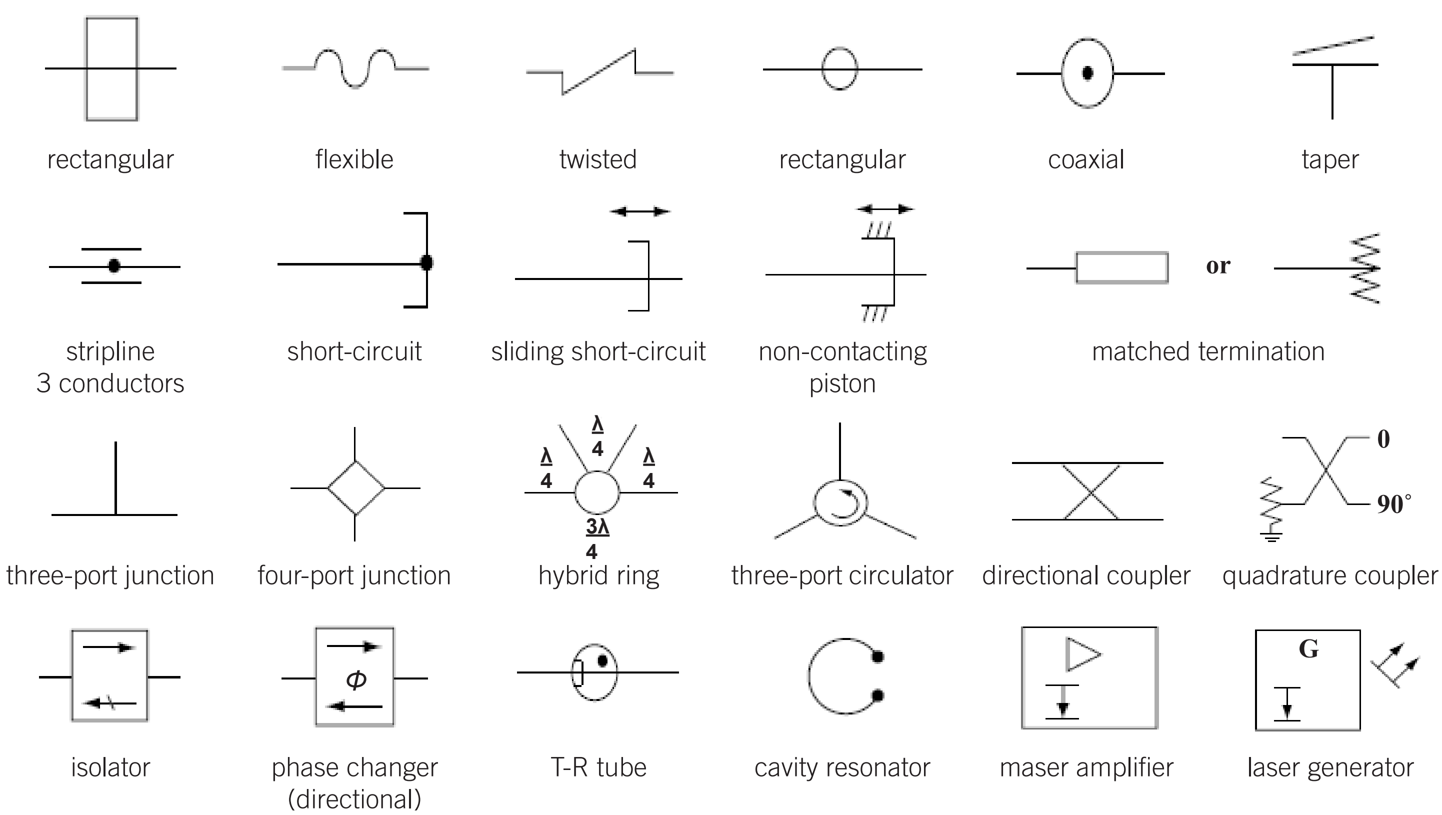


guided light devices

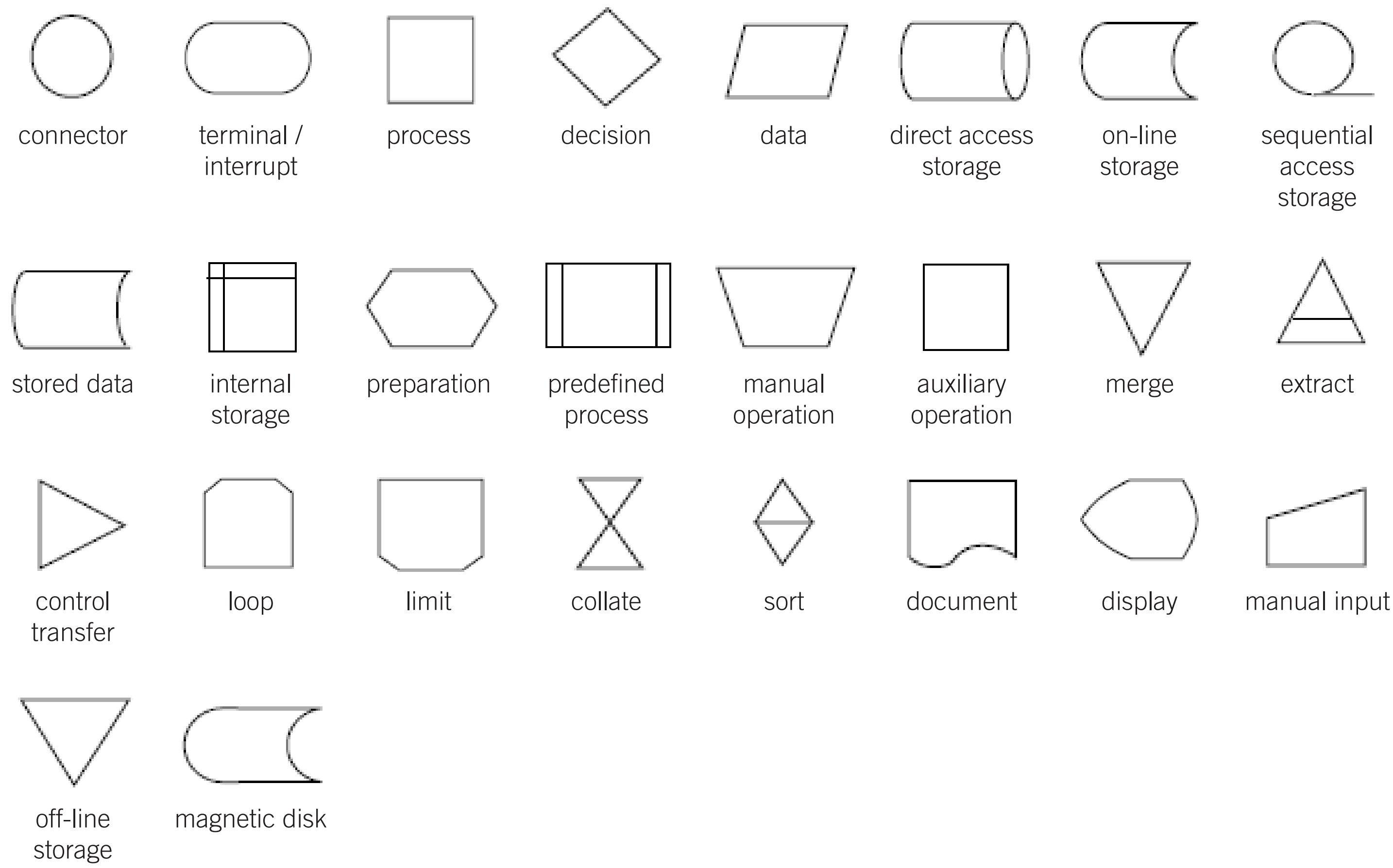
Telecommunication symbols



Microwave devices



Flowchart symbols



13. Some Abbreviations

Commonly used abbreviations in optical, logic and microprocessor circuits

Abbreviation	Description	Abbreviation	Description
ACC	accept	INH	inhibit
ACK	acknowledge	INT	interrupt
ADR	address	I/O	input / output
ALU	arthmetic logic unit		
		LD	load
BCD	binary code decimel	LOG 1	logical one
BCTR	bit counter	LOG Z	logical zero
BIN	binary	LSB	least-significant bit
BPS	bits per second		
BUF	buffer	MAR	memory address register
BUS	bus	MM	main memory
B	byte	MPX	multiplex
		MR	memory register
CAR	carry	MSB	most significant bit
CC	condition code	MUX	multiplexor
CE	chip enabled	µP	microprocessor
CLK	clock		
CLR	clear	N	negation
COMP	compare		
CP	clock pulse	OCT	octal
CR	clock register	OP	operation
CT	count		
CTR	counter	PAR	parity
CY	cycle	PC	program counter
		PE	parity error
D	data	PU	pull up
DEC	decimal		
DEL	delay	RAM	random access memory
DIN	data in	REG	register
DOUT	data out	RES	reset
DR	data register	RO	read out
DRAM	dynamic random access memory	ROM	read only memory
		RUN	run
EN	enable		
END	end	SET	set
EPROM	electronic programmable read only memory	SH	shift
ERASE	erase	SRAM	static random access memory
ERR	error	START	start
EXOR	exclusive or	STOP	stop
		STR	storage
F	function	SYNC	synchronisation
FF	flip-flop		
FIFO	first in - first out	TERM	terminate
		TO	to (transfer)
G	gate	TP	time pulse
GEN	generate	TRIG	trigger
GND	ground		
		WI	write in
HEX	hexidecimal	WR	write

Component identification abbreviations

Abbreviation	Description	Abbreviation	Description
AE	aerial	**L**	inductor
		LK	link
B	battery	**LP**	lamp
BB	busbar	**LS**	loudspeaker
C	capacitor	**M**	motor
CB	circuit breaker	**ME**	meter
CK	clock	**MG**	motor generator
CON	contactor	**MIC**	microphone
CSR	controlled semicondustor rectifier	**MK**	morse key
		ML	module
D	diode	**MT**	telephone handset
		MX	matrix
EQ	equaliser		
		PCC	photoconductive cell
F	fan	**PEC**	photoelectric cell
FB	ferrite disc or bead	**PL**	plug
FC	ferrite core		
FL	filter	**RE**	recording instrument or meter
FS	fuse		
FW	field winding	**SD**	surge diverter of any type
		SE	sealing end
G	generator	**SEM**	semaphore indicator
		SHW	shunt winding
H	heater	**SRAM**	static random access memory
HC	heat coil	**SW**	seires winding
HD	hydrophone		
		TD	transductor
IC	integrated circuit	**TL**	telephone receiver
IREG	induction regulator		
ISL	isolator	**U**	unit
K	key	**VB**	vibrator

14. Letter and Digit Code for R & C Values

For resistors, R, K, M, G and T are used as multipliers for 1, 10^3, 10^6, 10^9 and 10^{12}, respectively, of resistance values expressed in ohms, whilst for capacitors, p, n, µ, m and F are used as multipliers for 10^{-12}, 10^{-9}, 10^{-6}, 10^{-3} and 1, respectively, of the capacitance values expressed in farads.

For example:

Resistance values	Coded marking	Capacitance values	Coded marking
0.15 Ω	R15	0.15 pF	p15
1.5 Ω	1R5	1.5 pF	1p5
15.0 Ω	15R	15.0 pF	15p
1.5 kΩ	1K5	1.5 nF	1n5
150 kΩ	150K	150 nF	150n
1.5 MΩ	1M5	1.5 µF	1µ5
15 MΩ	15M	15 µF	15µ
1.5 GΩ	1G5	1.5 mF	1m5
1.5 TΩ	1T5	15 mF	15m

Appendix A

List of Standards used in complilation of 'Units & Symbols'

British Standards Institution (BSI) Publications

BS 3363: 1988	Letter symbols for semiconductor devices and integrated microcircuits
BS 3939: 1992	Graphical symbols for electrical power, telecommunications and electronics diagrams
BS 4058: 1995	Data processing flow chart symbols, rules and conventions
BS 5070: 1991	Engineering diagram drawing practice. Part 4: recommendations for logic diagrams
BS 5555: 1993	SI Units and recommendations for the use of their multiples (ISO 1000: 1992) and of certain other units
BS 5775: 1993	Quantities, units and symbols. Part 5: electricity and (ISO 31: 1992) magnetism. Part 11: mathematical signs and symbols for use in the physical sciences and technology

Note: The information given in the Booklet is in accordance (where relevant) with the Council* Directive on Units of Measurement (1991).

*The Council of the European Communities

Appendix B

Typefaces used

English Alphabet

Upper case upright	Lower case upright	Upper case sloping	Lower case sloping
A	a	*A*	*a*
B	b	*B*	*b*
C	c	*C*	*c*
D	d	*D*	*d*
E	e	*E*	*e*
F	f	*F*	*f*
G	g	*G*	*g*
H	h	*H*	*h*
I	i	*I*	*i*
J	j	*J*	*j*
K	k	*K*	*k*
L	l	*L*	*l*
M	m	*M*	*m*
N	n	*N*	*n*
O	o	*O*	*o*
P	p	*P*	*p*
Q	q	*Q*	*q*
R	r	*R*	*r*
S	s	*S*	*s*
T	t	*T*	*t*
U	u	*U*	*u*
V	v	*V*	*v*
W	w	*W*	*w*
X	x	*X*	*x*
Y	y	*Y*	*y*
Z	z	*Z*	*z*

Appendix B

Typefaces used

Greek Alphabet

	Upper case upright	Lower case upright	Upper case sloping	Lower case sloping
alpha	Α	α	*Α*	*α*
beta	Β	β	*Β*	*β*
gamma	Γ	γ	*Γ*	*γ*
delta	Δ	δ, δ*	*Δ*	*δ*
epsilon	Ε	ε	*Ε*	*ε*
zeta	Ζ	ζ	*Ζ*	*ζ*
eta	Η	η	*Η*	*η*
theta	Θ	θ	*Θ*	*θ*
iota	Ι	ι	*Ι*	*ι*
kappa	Κ	κ	*Κ*	*κ*
lambda	Λ	λ	*Λ*	*λ*
mu	Μ	μ	*Μ*	*μ*
nu	Ν	ν	*Ν*	*ν*
xi	Ξ	ξ	*Ξ*	*ξ*
omicron	Ο	ο	*Ο*	*ο*
pi	Π	π	*Π*	*π*
rho	Ρ	ρ	*Ρ*	*ρ*
sigma	Σ	σ	*Σ*	*σ*
tau	Τ	τ	*Τ*	*τ*
upsilon	Υ	υ	*Υ*	*υ*
phi	Φ	φ	*Φ*	*φ*
chi	Χ	χ	*Χ*	*χ*
psi	Ψ	ψ	*Ψ*	*ψ*
omega	Ω	ω	*Ω*	*ω*

*Used only for partial differential coefficients

The Institution of Engineering and Technology

IET Offices

London
Savoy Place
2 savoy Place
London
WC2R 0BL
United Kingdom
T: +44 (0)20 7344 5479
F: +44 (0)20 7240 7735
www.savoyplace.co.uk

New Jersey
379 Thornall Street
Edison NJ 08837
USA
T: +1 (732) 321 5575
F: +1 (732) 321 5702

Hong Kong
4412-13 Cosco Tower
183 Queen's Road Central
Hong Kong
T: +852 2521 2140
F: +852 2778 1711

Stevenage
Michael Faraday House
Six Hills Way
Stevenage
SG1 2AY
United Kingdom
T: +44 (0)1438 313311
F: +44 (0)1438 765526
E: postmaster@theiet.org
www.theiet.org

Beijing
Suite G/10F
China Merchants Tower
No. 118 Jianguo Road
Chaoyang District
Beijing
China
100022
T: +86 10 6566 4687
F: +86 10 6566 4647
E: china@theiet.org
www.theiet.org.cn

Bangalore
Unit No. 1103, 11th Floor
West Wing
Reheja Towers
MG Road
Bangalore
India
560 001
T: +91 (80) 4149 8080
or +91 (80) 4089 2222
F: +91 (80) 4089 2233
E: india@theiet.org