Designing potcore inductors

Potcores offer many advantages when you need to use an inductor in a circuit. This article details a simplified design method for two common potcore sizes based on a nomograph.

FERRITE POTCORES are widely used in the construction of small inductors and transformers. However very few amateurs know how to choose a core appropriate to their needs, or how to wind a coil of specific inductance.

This article describes a simple method of designing coils for low frequency applications. The design of coils for high frequency applications, and of transformers, is beyond the scope of this article. Design details given apply only to the Philips 'P' series of pot cores and more particularly to the 18 mm (P18/11) and 26 mm (P26/16) diameter cores which are the most commonly available.

Each core size is available in four different ferrite materials (3H1, 3B7, 3D3, 4C6) to cover the frequency range from audio to about 20 MHz. Additionally each material, in each size, is available with a number of permeabilities to cover different inductance, stability and Q factor requirements.

There are two factors commonly used to classify ferrite cores. These are effective permeability (μe) and A_L factor.

The μe factor is primarily determined by the permeability of the material used and its cross sectional area, and secondly by the air gap left between the centres of the two core halves. For example an 18 mm 3B7 core without any air gap (type 0 4000) has a μe of 1750 and a tolerance on inductance of ±25%. The use of increasingly larger air gaps in the same core size and material lowers the μe but increases the stability and reduces the tolerance on inductance.

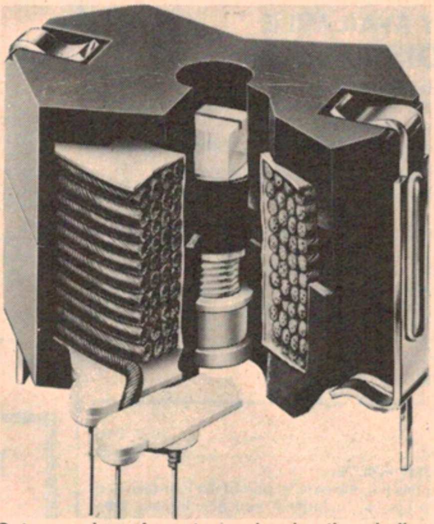
A second factor in common usage is A_L. This factor gives, in nanohenries, the inductance of ONE turn on the core. The inductance of N turns on the core is

$L = N^2 A_L \times 10^{-3}$ millihenries

The selection of a core size, a core material, a permeability value, a wire size and the number of turns depends on all the following factors:-

— inductance, stability of inductance
— frequency range
— Q factor
— unbalanced dc coil current
— level of ac coil current

Choosing the correct core taking *all* these factors into account is a difficult task indeed. However a large number of core types are eliminated by first selecting in accordance with frequency range and stability.



Cutaway view of a potcore showing the winding on the internal bobbin and the inductance adjustor in the centre. The ferrite 'pot' comes in two halves, held together with a clip.

Frequency range

Firstly select the core material from Table 1 in accordance with the desired frequency range. To choose between 3H1 and 3B7 it is necessary to consider temperature stability.

If the tuning capacitors associated with the coil have small or varying temperature coefficients, a 3B7 core should be used as they have the lowest temperature coefficient in the range 0° - 70°C. Alternatively, if using polystrene capacitors (temp. coeff. −150 ppm/°C) a 3H1 core having an effective permeability (μe) around 150 will give excellent temperature compensation for the temperature coefficient of these capacitors.

Inductance stability

Since the inductance of a coil is proportional to core permeability, the change of effective permeability (μe) with temperature determines the stability of inductance.

TABLE 1

FREQUENCY RANGE	CORE TYPE
0.1 — 200 kHz	3B7, 3H1
200 kHz — 2 MHz	3D3
2 MHz — 20 MHz	4C6

The percentage change of inductance with temperature is linearly proportional to μe and hence low μe cores should be used for greatest stability. Stability is therefore obtained at the expense of inductance obtainable with a given core size.

The temperature effect is not large enough to affect any but the most critical of applications and the tolerance on inductance as stated in Tables 2 and 3 will be obtained over the temperature range +15° to +35°C.

Direct current

A direct current in the winding will change the inductance value of the core and if large enough, could cause saturation. In general, large air gaps, and hence lower permeability (μe), cores should be used where large dc currents are flowing.

Q factor

The Q of a coil is influenced by different factors at different frequenceis.

At frequencies below 10kHz it is almost completely determined by the dc resistance of the winding. The Q factor of any given coil increases linearly with frequency, and the larger the core, the larger the Q. The highest Q factors are obtainable by using gapless cores of 3H1 or 3B7 material (providing that tolerance and stability are acceptable) eg. 04000 series (P18/11) and 08000 series (P26/16).

Throughout the ultrasonic range core and winding losses affect Q, but Q factors of several hundred may still be obtained by optimum choice of wire and core, such that core and winding losses are equal. For further information, on optimum design, reference should be made to Philips Data Handbook — Components and Materials, Vol. 4.

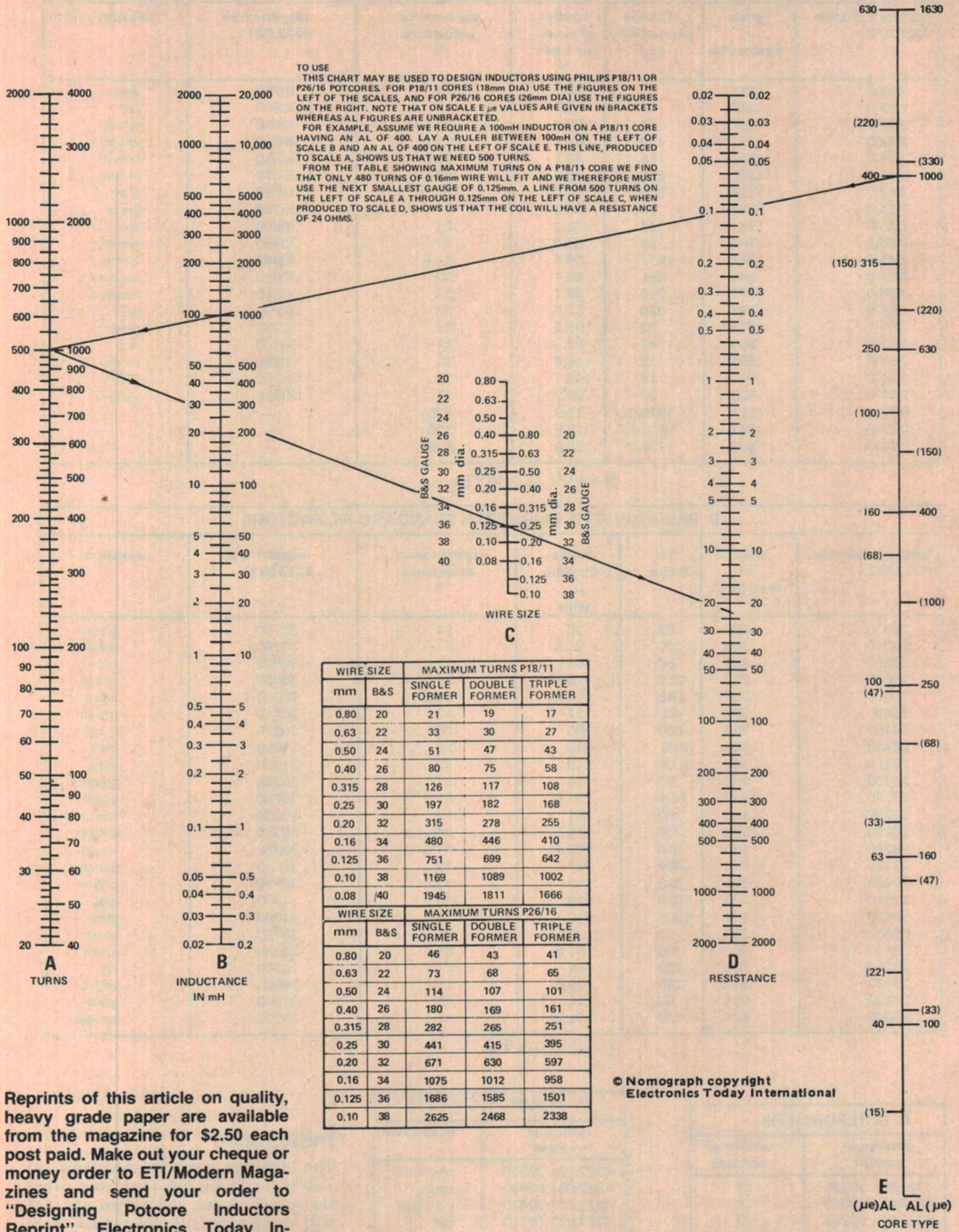
At higher ultrasonic and lower radio frequencies, additional factors of dielectric and skin-effect losses and parallel winding capacitance, all affect Q, making exact design difficult. Use of Litz wires, split section formers and small cores with low μe values will assist.

TO USE

THIS CHART MAY BE USED TO DESIGN INDUCTORS USING PHILIPS P18/11 OR P26/16 POTCORES. FOR P18/11 CORES (18mm DIA) USE THE FIGURES ON THE LEFT OF THE SCALES, AND FOR P26/16 CORES (26mm DIA) USE THE FIGURES ON THE RIGHT. NOTE THAT ON SCALE E µe VALUES ARE GIVEN IN BRACKETS WHEREAS AL FIGURES ARE UNBRACKETED.

FOR EXAMPLE, ASSUME WE REQUIRE A 100mH INDUCTOR ON A P18/11 CORE HAVING AN AL OF 400. LAY A RULER BETWEEN 100mH ON THE LEFT OF SCALE B AND AN AL OF 400 ON THE LEFT OF SCALE E. THIS LINE, PRODUCED TO SCALE A, SHOWS US THAT WE NEED 500 TURNS.

FROM THE TABLE SHOWING MAXIMUM TURNS ON A P18/11 CORE WE FIND THAT ONLY 480 TURNS OF 0.16mm WIRE WILL FIT AND WE THEREFORE MUST USE THE NEXT SMALLEST GAUGE OF 0.125mm. A LINE FROM 500 TURNS ON THE LEFT OF SCALE A THROUGH 0.125mm ON THE LEFT OF SCALE C, WHEN PRODUCED TO SCALE D, SHOWS US THAT THE COIL WILL HAVE A RESISTANCE OF 24 OHMS.



WIRE SIZE		MAXIMUM TURNS P18/11		
mm	B&S	SINGLE FORMER	DOUBLE FORMER	TRIPLE FORMER
0.80	20	21	19	17
0.63	22	33	30	27
0.50	24	51	47	43
0.40	26	80	75	58
0.315	28	126	117	108
0.25	30	197	182	168
0.20	32	315	278	255
0.16	34	480	446	410
0.125	36	751	699	642
0.10	38	1169	1089	1002
0.08	40	1945	1811	1666

WIRE SIZE		MAXIMUM TURNS P26/16		
mm	B&S	SINGLE FORMER	DOUBLE FORMER	TRIPLE FORMER
0.80	20	46	43	41
0.63	22	73	68	65
0.50	24	114	107	101
0.40	26	180	169	161
0.315	28	282	265	251
0.25	30	441	415	395
0.20	32	671	630	597
0.16	34	1075	1012	958
0.125	36	1686	1585	1501
0.10	38	2625	2468	2338

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Table 2 P18/11 Potcores

A. PRE-ADJUSTED PAIRS WITH STANDARD μ_e VALUES						
catalogue number 4322.022 . . .	grade of ferroxcube	effective permeability (μ_e)	number of turns for 1 mH $\propto$	tolerance on inductance %	adjustor type 4322.021	adjustor colour
28030	3B7	33	98.2	±1	30780	green
28040	3B7	47	82.3	±1	30800	red
28050	3B7	68	68.4	±1	30980	white
28060	3B7	100	56.4	±1.5	30980	white
28070	3B7	150	46.1	±2	30810	brown
28080	3B7	220	38.1	±3	30810	brown
28090	3B7	330	31.0	±3	31090	grey
28230	3H1	33	98.2	±1	30780	green
28240	3H1	47	82.3	±1	30800	red
28250	3H1	68	68.4	±1	30980	white
28260	3H1	100	56.4	±1.5	30980	white
28270	3H1	150	46.1	±2	30810	brown
28280	3H1	220	38.1	±3	30810	brown
28290	3H1	330	31.0	±3	31090	grey
28430	3D3	33	98.2	±1	30780	green
28440	3D3	47	82.3	±1	30800	red
28450	3D3	68	68.4	±1	30980	white
28810	4C6	15	146	±1	30780	green
28830	4C6	33	98.2	±1	30790	yellow
08000	3B7	1910.0	12.9	±25	–	–
08200	3H1	1910.0	12.9	±25	–	–
08400	3D3	730.0	20.8	±25	–	–

$N = \propto\sqrt{L}$ (L in 10^{-3} H)

B. PRE-ADJUSTED PAIRS WITH STANDARD AL FACTORS						
catalogue number 4322.022 . . .	grade of ferroxcube	AL factor	corres-ponding μ_e value	tolerance on inductance %	adjustor type 4322.021	adjustor colour
29030	3B7	63	20	±1	30780	green
29040	3B6	100	31.8	±1	30780	green
29050	3B7	160	51	±1	30800	red
29060	3B7	250	79.5	±1	30980	white
29070	3B7	315	100.2	±1.5	30980	white
29080	3B7	400	127	±2	30810	brown
29100	3B7	630	200	±3	30810	brown
29110	3B7	1000	318	±3	31090	grey
29120	3B7	1600	510	±3	31090	grey
29230	3H1	63	20	±1	30780	green
29240	3H1	100	31.8	±1	30780	green
29280	3H1	160	51	±1	30800	red
29260	3H1	250	79.5	±1	30980	white
29270	3H1	315	100.2	±1.5	30980	white
29280	3H1	400	127	±2	30810	brown
29300	3H1	630	200	±3	30810	brown
29310	3H1	1000	318	±3	31090	grey
29320	3H1	1600	510	±3	31090	grey
29430	3D3	63	20	±1	30780	green
29440	3D3	100	31.8	±1	30780	green
29450	3D3	160	51	±1	30800	red
29460	3D3	250	79.5	±1	30980	white
29830	4C6	63	20	±1	30780	green
29840	4C6	100	31.8	±1	30790	yellow

$L = N^2 AL$ (10^{-9} H)

C. COILFORMERS	
catalogue number	number of sections
4322.021.30330	1
4322.021.30340	2
4322.021.30350	3
4322.021.30130	1 with pins
4302.021.20030	1 with pins

D. MOUNTING PARTS	
catalogue number	description
4322.021.30550	container
4322.021.30660	spring
4322.021.30470	tag plate
4322.021.30710	nut
4322.021.30720	bush
4302.021.20020	clip

Inductance

The tolerance given on inductance, in Tables 2 and 3 is obtained when using the specified core, and a wire size that will completely fill the former close layer wound. Due to slight changes in wire diameter and different methods of winding, the exact number of turns accommodated may vary by ±10%.

Table 3 P26/16 Potcores

A. PRE-ADJUSTED PAIRS WITH STANDARD μ_e VALUES

catalogue number 4322.022	grade of ferroxcube	effective permeability (μ_e)	number of turns ∝	tolerance on inductance %	adjustor type number 4322,021 ...	adjustor colour
24030	3B7	33	120	±1	30760	green
24040	3B7	47	100.5	±1	30770	red
24050	3B7	68	83.6	±1	30960	yellow
24060	3B7	100	68.9	±1.5	30970	white
24070	3B7	150	56.3	±2	30730	brown
24080	3B7	220	46.5	±3	31080	grey
24230	3H1	33	120	±1	30760	green
24240	3H1	100.5	100.5	±1	30770	red
24250	3H1	68	83.6	±1	30960	yellow
24260	3H1	100	68.9	±1.5	30970	white
24270	3H1	150	56.3	±2	30730	brown
24280	3H1	220	46.5	±3	31080	grey
24430	3D3	33	120	±1	30760	green
24440	3D3	47	100.5	±1	30770	red
24450	3D3	68	83.6	±3	30960	yellow
24810	4C6	15	178	±1	30760	green
24820	4C6	22	147	±1	30770	red
24830	4C6	33	120	±1	30970	white
04000	3B7	1750	16.5	±25	—	—
04200	3H1	1750	16.5	±25		
04000	3D3	705	25.9	±25		

$N = \alpha \sqrt{L}$ (L in 10^{-3} H)

B. PRE-ADJUSTED PAIRS WITH STANDARD AL FACTORS

catalogue number 4322.022	grade of ferroxcube	AL factor	corres-ponding μ_e value	tolerance on inductance ∝	adjustor type 4322.021 ...	adjustor colour
25030	3B7	63	30	±1	30760	green
25040	3B7	100	47.5	±1	30770	red
25050	3B7	160	76	±1	30960	yellow
25050	3B7	250	119	±1.5	30970	white
25070	3B7	315	149	±2	30730	brown
25080	3B7	400	190	±2	31080	grey
25100	3B7	630	298	±3	31080	grey
25230	3H1	63	30	±1	30760	green
25240	3H1	100	47.5	±1	30770	red
25250	3H1	160	76	±1	30960	yellow
25260	3H1	250	119	±1.5	30970	white
25270	3H1	315	149	±2	30730	brown
25280	3H1	400	190	±2	31080	grey
25300	3H1	630	298	±3	31080	grey
25420	3D3	40	19.0	±1	30760	green
25430	3D3	63	30	±1	30760	green
25440	3D3	100	47.5	±1	30770	red
25450	3D3	160	76	±1	30960	yellow
25810	4C6	25	11.9	±1	30760	green
25820	4C6	40	19.0	±1	30770	red
25830	4C6	63	30	±1	30970	white

C. COIL FORMERS

catalogue number	number of sections
4322.02130270	1
4322.021.30280	2
4322.021.30290	3
4322.021.30090	1 with pins
4302.021.20010	1 with pins

C. MOUNTING PARTS

catalogue number	description
4322.021.30530	container
4322.021.30640	spring
4322.021.30450	tag plate
4322.021.30710	nut
4322.021.30720	bush
4302.021.20000	clip

Hence it is safer, when winding experimental coils, to only try and fit 90% of the turns indicated in the maximum number of turns tables.

If the former is only partly filled, errors up to 4% may occur with the lower μe cores. However the use of an adjustor will allow a +10% adjustment range which is generally sufficient to cope with tolerances found in practical circuits.

When optimum stability is required the type of adjustor that matches a certain core should be used. If it is desired to widen the adjustable range, at the possible expense of stability, an adjustor indicated for a potcore with a high μe value may be used with a potcore of low μe value.

Design data for this article has been derived from the Philips publication "Ferroxcube Potcores", 1972. Nomograph copyright — Electronics Today International. This article was originally published in the October 1974 issue of ETI, Australian edition.