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Design of OPT-1A continued....

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14. Calculate minimum centre leg cross sectional area, Afe.

Confirm RLa-a minimum and maximum power at clipping.

OPT-1A. From Previous Steps, RLa-a min = 4,500 ohms,
Max PO = 72 Watts.

Afe = 300 x sq.rt (audio power, Watts), in sq.mm.

NOTE. This formula has been derived from a basic formula for core size used for mains transformers,
Afe = sq.root power input / 4.4 where the Afe is in sq inches.
This old formula is based on B being about 1 Tesla, or 10,000 gauss at 50Hz but for audio hi-fi Bac max should be less than 0.5 Tesla for an OPT at 50Hz.
After considerable trials I found the above formula is a good guide for PP audio OPT.

OPT-1A1, Theoretical Afe, thAfe = 300 x sq.rt 72
= 300 x 8.49 = 2,547 sq.mm

15. Calculate the core tongue dimension, T.

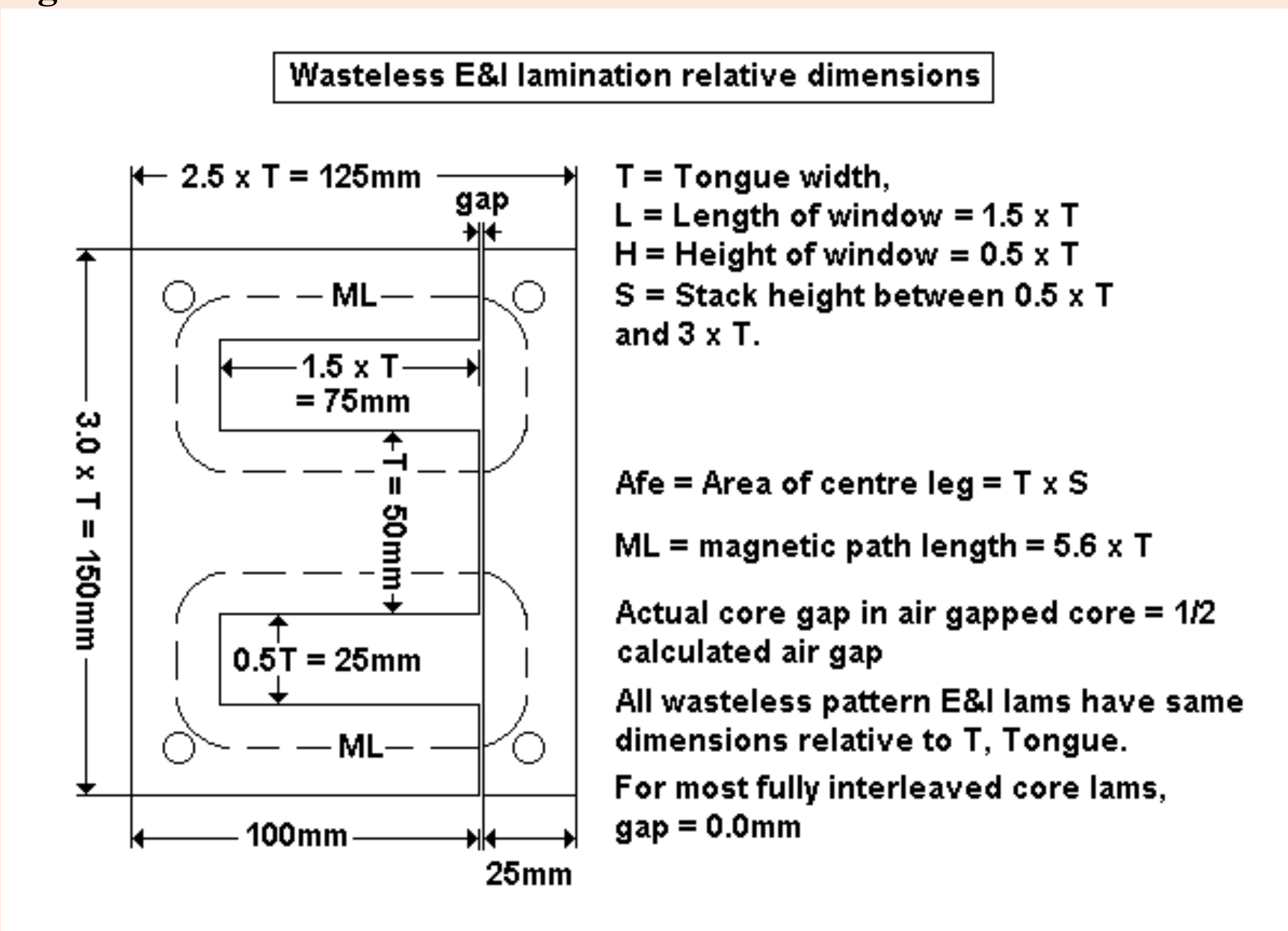
For a square core section, Tongue dimension = Stack height, ie, T = S.

Theoretical T x Theoretical S = th Afe, sq.mm.
Therefore theoretical T dimension = square root th AFe = Th T, mm

OPT-1A, thT = sq.rt 2,547 = 50.46mm.

Choose suitable standard T size from list of available wasteless E&I lamination core materials with assembled E&I plan sizes of :-

Fig 8.



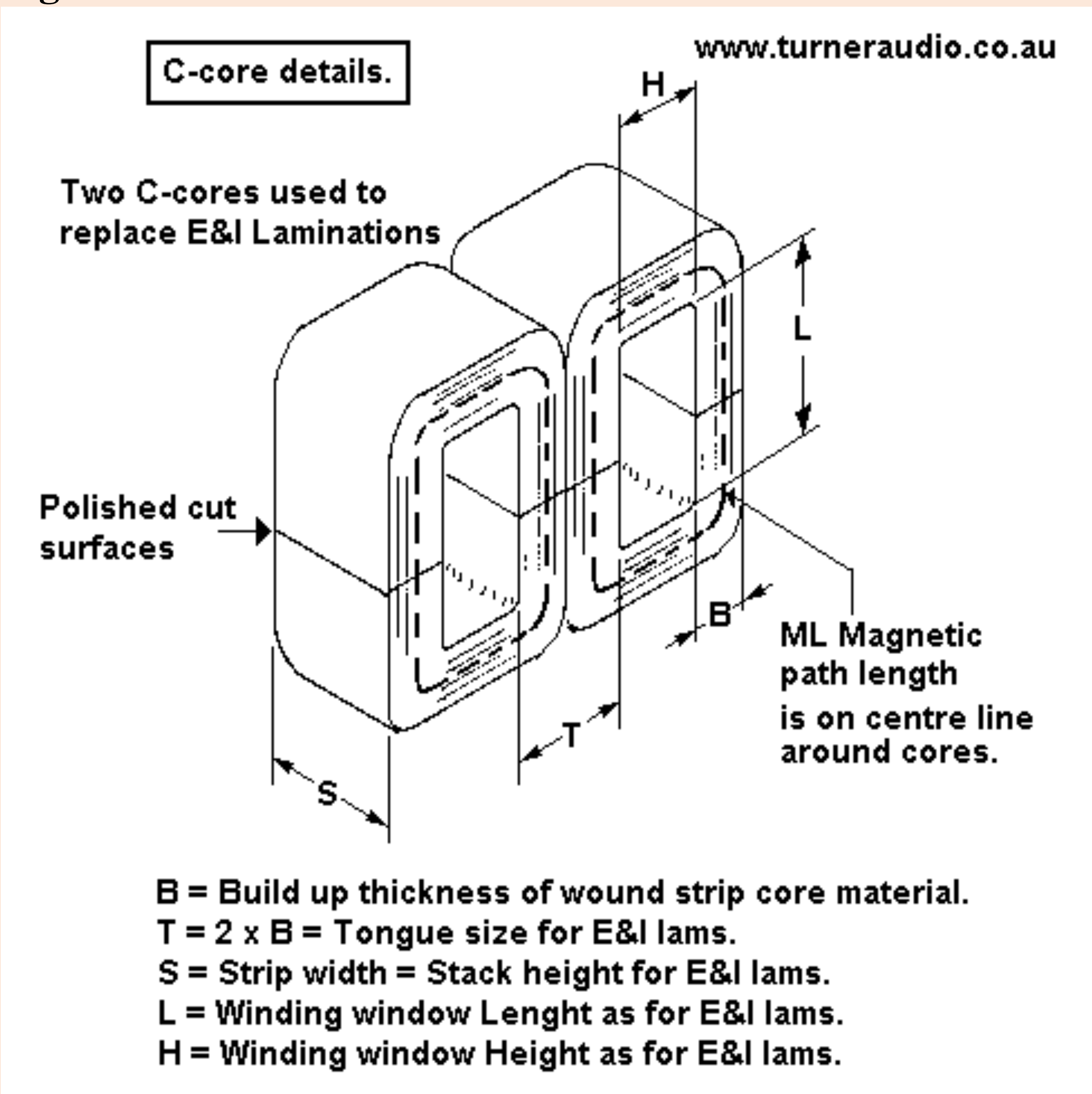
T sizes commonly available for wasteless OPTs :-
20mm, 25mm, 32mm, 38mm, 44mm, 50mm, 62.5mm

NOTE. The thT calculated = 50.45mm, which indicates the standard size of T = 50mm may possibly be best.
But using one size smaller should be tried because it has been found that the weight may be slightly less if the aspect ratio gives a Stack height more than Tongue dimension. If it is found to be difficult to get low winding losses with the slightly lower T size, the stack height may be increased to reduce the number of primary and secondary turns so thicker wire with less resistance may be used.

NOTE. Choosing a standard T size above thT gives lower copper winding losses, higher weight, and choosing T below thT gives higher losses and lower weight. Afe must be the same for either T = 44mm or 50mm so the LF response and Fsat does not change with tongue size. HF peformance depends entirely upon the interleaving geometry and insulations.

OPT-1A, choose core T = 44mm

Fig 9.



NOTE. Some constructors will be using non wasteless pattern E&I lams, or C cores which do not have the same relative dimensions as E&I Wasteless Pattern cores.

The actual sizes of the T, S, H, & L of the core to be used must be carefully considered.

Other lamination patterns or C-cores have a much larger window area for their effective T dimension so that larger wire sizes for less copper loss may be employed or to give more room for more turns and insulation layers. Regardless of the core pattern, the ratio of Afe size relative to Bac max must be maintained.

16. Calculate theoretical Stack height.

thS = Afe / T, then adjust to a larger height to suit nearest standard plastic bobbin size if available, mm.

OPT-1A, S = 2,547 / 44 = 57.8mm. This is more than 10% above a standard size bobbin allowing stack height of 50mm, so a hand made bobbin should be used, say 45mm x 60mm maximum hole size, with **stack = 59mm.**

17. Confirm sizes for core.

Adjusted Afe = chosen T x chosen S, sq.mm

OPT-1A. Adjusted Afe = 44 x 59 = 2,596sq.mm
T = 44mm, H = 22mm, L = 66mm, S = 59mm.

18. Calculate the theoretical primary turns, thNp.

thNp = square root (PRL x PO) x 10,000 / Afe = thNp, no of turns.

NOTE. The formula here is derived from more complex and complete formula taking Bac max and F into account. If we want magnetic field strength Bac = 1.6 Tesla, and F = 14 Hz, which is a suitably low F for where saturation is commencing, and express V in terms of load and power, we get the above short easy equation for primary turns required. The full formula for calculating B is in steps below where the design is checked. The V factor can be expressed as sq.root of (Primary RL x power output) as in the above simplified equation.

RL = 4,500 ohms, PO = 71, Afe = 2,244sq.mm from previous steps,
OPT-1A. ThNp = sq.rt(4,500 x 72) x 10,000 / 2,596 = **2,192 turns.**

19. Calculate theoretical Primary wire dia, thPdia.

NOTE. The Primary wire used for the transformer will occupy a portion of the window area approximately = 0.28 x L x H. The constant of 0.28 works for most OPT.
Each turn of wire will occupy an area = overall dia squared.
Overall or oa dia is the dia including enamel insulation.
Therefore theoretical over all dia of P, thoaPdia, of wire including enamel insulation = square root (0.28 x L x H / thNp), mm.

OPT-1A, th oa dia P wire = sq.rt (0.28 x 66 x 22 / 2,192)
= sq.rt 0.185 = **0.430 mm**

20. Find nearest suitable overall dia wire size from

the wire size table. oaPdia, mm

Table 1. Available Wire Sizes.

Cu wire dia mm	Overall dia, including enamel, mm	Cu wire dia mm	Overall dia, including enamel, mm	Cu wire dia mm	Overall dia, including enamel, mm
4.000	4.160	0.950	1.041	0.280	0.334
3.750	3.905	0.900	0.990	0.265	0.312
3.550	3.702	0.850	0.937	0.250	0.301
3.350	3.498	0.800	0.885	0.236	0.285
3.150	3.294	0.750	0.832	0.224	0.272
3.000	3.142	0.710	0.790	0.212	0.258
2.800	2.938	0.670	0.749	0.200	0.245
2.650	2.784	0.630	0.706	0.190	0.234
2.500	2.631	0.600	0.675	0.180	0.222
2.360	2.488	0.560	0.632	0.170	0.211
2.240	2.366	0.530	0.601	0.160	0.199
2.120	2.243	0.500	0.569	0.150	0.188
2.000	2.120	0.475	0.543	0.140	0.176
1.900	2.018	0.450	0.516	0.132	0.167
1.800	1.916	0.425	0.489	0.125	0.159
1.700	1.813	0.400	0.462	0.112	0.143
1.600	1.711	0.375	0.436	0.100	0.129
1.500	1.608	0.355	0.414	0.090	0.117
1.400	1.506	0.335	0.393	0.080	0.105
1.320	1.423	0.315	0.371	0.071	0.095
1.250	1.351	0.300	0.355	0.063	0.085
1.180	1.279	Metric winding wire sizes, 200C temp rated, polyester-imide enamel, GRADE 2.		0.060	0.081
1.120	1.217			0.056	0.076
1.060	1.155			0.050	0.068
1.000	1.093				

OPT-1A, Want oa dia not exceeding 0.43mm calculated in Step 19.
Try oa wire size = 0.414mm, with bare copper dia = 0.335 mm.

21. Caculate maximum safe working Idc.

Safe working direct current density rating for most OPTs
= 2Amps per square millimetre of copper cross sectional area for the wire.
This results in OPTs running cool.

Safe dc current, Idc = Ia rating x pye x (d squared / 4) Amps.
where Ia rating is Amps per sq.mm, pye = 22/7, d is copper wire dia in mm.

OPT-1A, Cu dia wire = 0.355mm, Rating 2A/sq.mm.
Safe Idc = 2 x 3.143 x 0.355 x 0.355 / 4 = 0.198 Amps dc.

Is this current rating more than 2 x idle current proposed?

Idle current = 50mAdc; 2 x Ia = 100mA, and well below wire rating;
Primary wire size is OK.

NOTE. If the Idc current density is kept below 2A/sq.mm, the heat dissipated in a winding is usually very low so winding heating does not need to be calculated. With 50mA Idc flow in 1/2 the primaryRwp of 57 ohms, heat in the wire = I squared x R = 0.1425 Watts. It must be remembered the primary wire may seriously over heat if bias failure occurs and with a saturated 6550 the Idc may reach 0.5 Amps, so heat in the P wire = 14.25 Watts, and the wire may get so hot it melts the OPT insulation, and insulation failure may occur. It is important to have active protection circuitry preventing Ia ever reaching more than about 150mA dc for longer than 4 seconds.

22. Calculate the bobbin winding traverse width.

NOTE. Bobbin traverse width, Bww, is the distance between the cheek flanges and varies depending on who made the bobbin, but it is common for each flange thickness to be about 2mm for many bobbins with T between 32mm and 62.5mm.
The winding traverese width affects the number of turns per layer.
Some tradesmen or women do not use moulded bobbins but use a simple rectangular tube former made with cut peices of 2mm fibre glass sheet and then use interlayer insulation extending to the full window length L. The winding layers start and stop at about 2mm short of the window size so Bww ends up being the same as for where a pre-moulded bobbin with 2mm cheek flanges is used. The advantage is minor, but for OPTs with HV, there is better "creepage distance" between each layer of wire as the path for an arc is much longer with "cheekless bobbins". Much more skill is needed for cheekless windings and so it is rarely ever used except by old guys who learnt their trade 60 years ago.

So, for design purposes, the winding will traverse a distance = L - 4mm.

OPT-1A, For core window L = 66mm, **Bww = 66 - 4 = 62 mm.**

23. Calculate no of theoretical P turns per layer.

ThPtpl = 0.97 x Bww / oa dia from Step 20.

NOTE. The constant 0.97 factor allows for imperfect layer filling.
Ignore fractions of a turn.

thPtpl = 0.97 x 62 / 0.414 = **145 Primary turns per layer.**

24. Calculate theoretical number of primary layers.

Then round down or up to convenient even number of layers.

Theoretical N pL = (Theoretical Np from step 18) / PtpL from step 23, then round up/down.

OPT-1A, thNpL = 2,192 / 145 = 15.11 layers; round UP to **16 layers.**

NOTE. Rounding down may reduce Np and raise Fs above wanted 14 Hz. But the actual turns used will give low enough Fs, in this case 14.4Hz, less than a 15% rise above design aim and OK. For those wanting to maintain Fs = 14Hz, or have Fs marginally lower than 14 Hz, the Afe can be increased by increasing S from say 59 mm to 62.5 mm or more and then be able to use a standard size of pre-made moulded bobbin 44mm x 62.5mm, and have Fs slightly lower.
The calculated number of primary layers should be an even number to avoid a primary winding CT in the middle of a layer which is awkward to wind, and because each 1/2 primary winding should have an equal number of turns and a symetrical geometric layout either side of the CT.

25. Calculate actual Np.

Np = Number of P layers from Step 23 x thPtpl from Step 23.

OPT-1A, Np = 16 x 145 = 2,320 turns.

26. Calculate average turn length, TL.

TL = (3.14 x H) + (2 x S) + (2 x T), mm.
where 3.14 is pye, or 22/7, and 2 are constants.

OPT-1A, TL = (3.14 x 22) + (2 x 59) + (2 x 44) = **275 mm.**

27. Calculate primary winding resistance, Rwp.

Rwp = 2.26 x (Np x TL) / (100,000 x Pdia x Pdia), ohms.
where 2.26 is the resistance of 100 metres of 1.0mm dia wire and a constant, and 100,000 is a constant, and P dia is the copper dia from the wire tables.

OPT-1A, PRwp = 2.26 x 2,320 x 275 / (100,000 x 0.355 x 0.355) = **114 ohms.**

28. Calculate pri winding loss % with minimum RLa-a,

P loss % = 100% x Rwp / (PRL + Rwp), %.

OPT-1A, P loss = 100% x 114 / (4,500 + 114) = **2.47%.**

29. Is the winding loss more than 3.0%?

If YES the design calculations must be checked and perhaps a larger core stack or window size chosen.
If NO, proceed to Step 30.

OPT-1A, P winding loss is less than 3.0%.

NOTE. The calculations so far are based on using the lowest likely RLa-a. Under optimal normal operation, RLa-a will be higher than the mimimum RLa-a for class AB1 and pure class A and give lower winding losses. Typical Middle Value RLa-a would be 2 x min RLa-a, or 9k0 in this case, and if so, winding losses will be 1/2 those for the 4k5. But for best design the OPT should have low winding losses even were RLa-a is a minimum value.

It is better to have low winding losses so that the primary windings are unlikely to overheat if a tube malfunctions and draws excessive Idc during a "bias failure event". Such occurences were a main reason why so many OPTs of the past failed so easily after being designed by accountants rather than engineers who know "shit happens" :-)

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