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47. Tapped Secondary Windings.

The example title for Tapped Secondaries will be OPT-1ATS, and will be used for 2 x 6550 or KT88 with Ea = +500V, Ia dc = 50mA in each tube at idle, and tube conditions are the same as OPT-1A.

Instead of using multiple secondary windings and varied links to give different load matches, it is possible to use Tapped Secondary Windings so that no adjustment of the Secondary turns Ns is done with a soldering iron.
The tapped secondaries may have each end of the windings plus two taps taken to 4 terminals at the rear of the amp for speakers.
These are usually labelled Common, 4 ohms, 8 ohms and 16 ohms.

Many amps just have Com, 4 ohms and 8 ohms.

NOTE.
The core sizes and primary turns will be the same as for OPT-1A.

48. Nominate the wanted load ratios and Sec turns.

The primary turns for OPT-1ATS = 2,320t, same as OPT-1A.

OPT-1ATS can have 4 speaker terminals, one is labelled COM which connects to the 0V rail. The other 3 terminals will be labelled 4 ohms, 8 ohms and 16 ohms.
The Tapped Secondary winding will be ONE non adjustable winding consisting of multiple identical windings each in parallel and all with identical tap positions for a wanted speaker impedance.

The load match at each terminals will be Middle RL-a of 9k0 to secondary = 3 ohms, 6 ohms or 12 ohms.
Np = 2,320 turns.

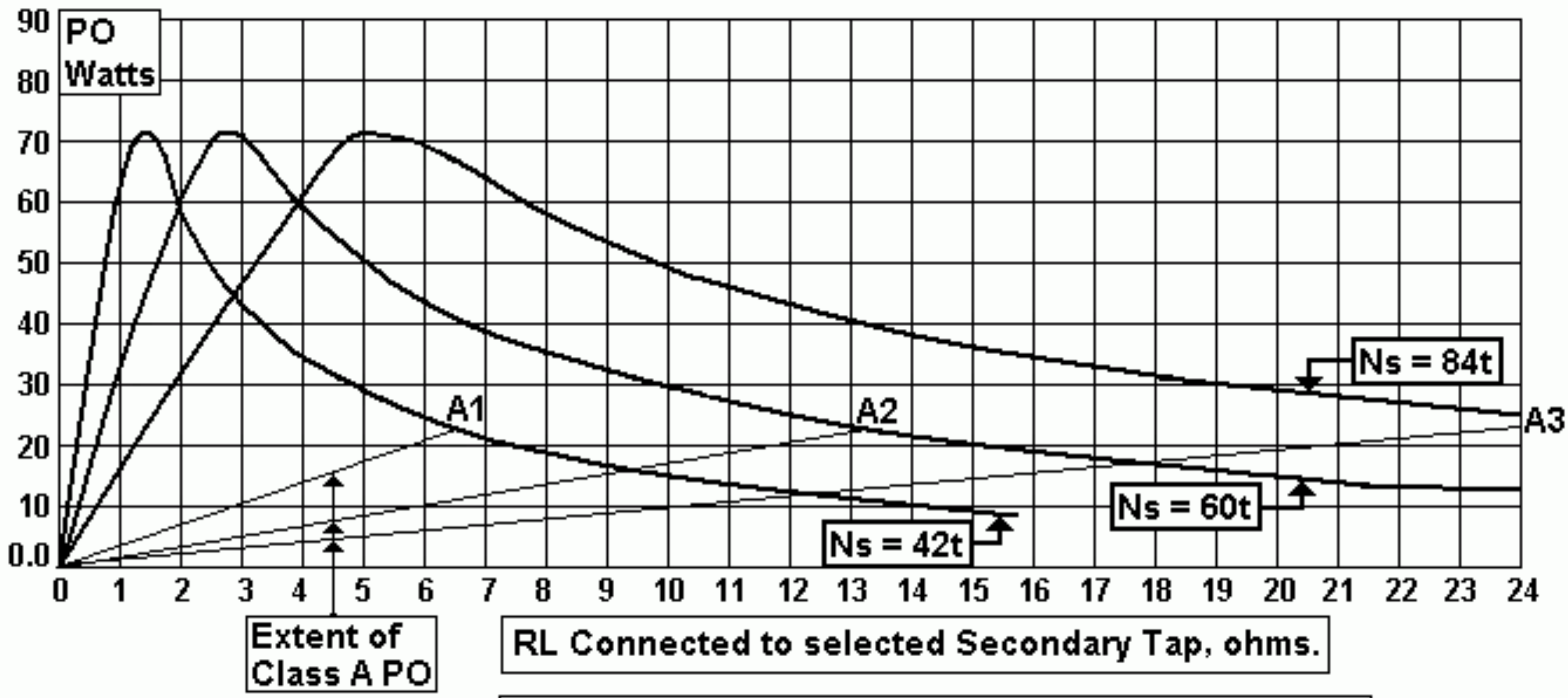
The 3 possible ZR and TR and Ns sec turns are
9,000 : 3 ohms, ZR = 3,000 : 1, TR = 54.77 : 1, Ns = 42 turns.
9,000 : 6 ohms, ZR = 1,500 : 1, TR = 38.73 : 1, Ns = 60 turns.
9,000 : 12 ohms, ZR = 750 : 1, TR = 27.39 : 1, Ns = 84 turns.

The possible range of output power and class of operation can be shown by the following set of graphs :-

Fig 26.

Graphs for PO from 3 different Sec turns on OPT-1ATS

For 2 x 6550 in PP, 40% UL, 12% CFB, Ea = +500Vdc, Eg2 min = +330Vdc,
Ia idle = 50mAdc, Pda at idle = 25 Watts each tube.
OPT-1ATS has Np = 2,320t, Ns = 42t or 60t or 84t selectable from tapped secondary.



		Secondary turns and loads and PO		
		42t	60t	84t
Primary turns,	Primary loads.	71 W AB	43 W AB	25 W AB
		5 W Class A	10.5 W class A	22 W class A
2,320t	4,500 ohms	1.5 ohms	3.0 ohms	6.0 ohms
2,320t	9,000 ohms	3.0 ohms	6.0 ohms	12.0 ohms
2,320t	18,000 ohms	6.0 ohms	12.0 ohms	24.0 ohms

See website for full explanations. www.turneraudio.com.au

How does anyone understand the **Fig 26** graph?

Let us consider the secondary has Ns = 84 turns. This is made up using multiple secondary sections interleaved between primary sections.
Each Sec section has 84turns and has taps at 42turns and 60 turns above the Common end of the 84 turns.

For OPT-1ATS, there will be 3 Turn Ratios and Impedance ratios available.
For 16 ohms, Ns = 84t, Np = 2,320t, TR = 27.62 : 1, ZR = 762.81 : 1.
For 8 ohms, Ns = 60t, Np = 2,320t, TR = 38.67 : 1, ZR = 1,495.11 : 1.
For 4 ohms, Ns = 42t, Np = 2,320t, TR = 55.24 : 1, ZR = 3,051.25 : 1.

Notice that the Com to 16 ohm whole Ns winding uses all 84t,
The Com to 8 ohms uses sq.rt (8 / 16) x 84t = 60t, to the nearest whole turn.

The Com to 4 ohms uses sq.rt (4 / 16) x 84t = 42t, to the nearest whole turn.

Consider that you wish to use the tap for Ns = 42 turns, labelled "4 ohms."

On **Fig 26**, Look at the horizontal axis for Secondary RL ohms and choose RL = 4 ohms. The maximum PO at clipping may be read from the Ns=42t curve for clipping which shows max PO for 4 ohms = 35W class AB, with he first 14W in class A. The load used with Ns = 42t could be as low as 1.5 ohms when one may expect max PO = 71W AB.
But if an 8 ohm speaker was used with Ns = 42t, the max PO = 19W, and it is all pure class A.

There are lines indicating the extent of class A.

For the Ns=42t curve there is a straight line between 0.0W & 0.0 ohms to Point A1 and power level below this line is all pure class A. All PO clipping levels to the right side of Point A1 will be pure class A. Point A1 indicates where PO = 23W and is the maximum possible pure class A level and it occurs with a load = 6.4 ohms.
It is impossible to achieve 23W of pure class A with a load lower than 6.4 ohms, but the class AB performance will be fine.

For where Ns = 60t, the Ns=60t curve has Point A2 for max pure class A when RL = 13 ohms.

For where Ns = 84t, the Ns=84t curve has Point A3 for max pure class A when RL = 26 ohms, just off the graph which goes up to only 24 ohms.

The safe minimum Secondary RL which will not cause tube overheating with a continuous sine wave may be read from the graphs at the peaks of each curve for maximum PO.

In previous design steps, Minimum safe RLa-a was calculated at 4,444 ohms.
For where Ns is the same for OPT-1A and OPT-1ATS, the secondary loads which are transformed at the primary to be the minimum safe RLa-a are :-
Com to 4, 42 turns, 1.4 ohms min,
Com to 8, 60 turns, 2.8 ohms min,
Com to 16, 84 turns, 5.6 ohms min.

The use of a speaker of say 4 ohms with Ns = 84t could damage the output tubes.
Maximum PO is 60W, which occurs to the left of the max PO of 71W with 5.6 ohms.

If the 4 ohm speaker was moved to the 8 ohm terminal with 60t, the max PO is also 60W, but the tubes will not overheat, as the 60W occurs to the right of max PO of 71W with 2.8 ohms.

The BEST QUALITY performance occurs with the 4 ohm speakers connected to the 4 ohm terminal with 42t.
PO = 35W with much pure class A. The 4 ohm speaker is most likely to have a minimum Z at perhaps 2.8 ohms so the use of the 4 ohm terminal gives up to 50W if Z dips to 2.8 ohms.

The use of all speakers above 4 ohms may be used on the 4 ohm terminal, and should be tried, and if there is no clipping, the sound will always be the best possible because THD/IMD is lowest possible, and damping factor highest.

49. Calculate available height for layers of secondary.

For a Tapped Secondary, the interleaving pattern will be chosen as in **Step 30.**

Each Secondary section may have more than one layer of secondary wire.

All Secondary sections chosen in any P-S interleaving pattern will be identical.

The number of turns in each Secondary section will always suit the highest load.

Where one layer of wire is used for a secondary section, all the turns in the layer must give a match to the highest Sec load to be used say 16 ohms.

Where there are two layers of wire in a secondary section, one layer gives a match to 1/4 of the highest load to be used, say 4 ohms.

OPT-1ATS, Interleaving pattern will be 5P + 4S sections.

Calculate Available Sec height =
(Max total avail wind ht within bobbin) - (Height of Primary, plus all insulations).

Confirm Available height within bobbin = 0.8 x 22mm = 17.6mm.
Confirm height of primary wires = 16 layers x 0.414mm oa P dia = 6.62mm.

List all most likely insulation layers to be used, same as in OPT-1A :-
0.05mm insulation pri-pri layers, i, height = 9 x 0.05 = 0.45mm.
0.5mm insulation between anode primary and cathode primary = 2 x 0.5 = 1.0mm.
0.5mm insulation between anode and cathode primaries and secondary = 8 x 0.5 = 4.0mm.

Total thickness of all insulation = 5.45mm.

OPT-1ATS, Calculate Available Sec height = 17.6 - (6.62 + 5.45) = 5.55mm.

50. Calculate the max theoretical oa dia of secondary wire.

Calculate available height for one secondary section.
Section height = total secondary height from Step 49 / No of Sec sections
= 5.55mm / 4 = 1.3875mm.

Calculate Sec wire size, oa dia.

NOTE. The turns for each secondary section have already been calculated in Step 48 as the maximum number of turns for highest Sec load.

Confirm max turns per Sec section 84 turns.

Estimate possible layers of wire for each Sec section and oa wire dia.

Possibility 1. There are 84t for one layer, oa dia = Bww / Ns
= 62mm / 84 turns = 0.738mm.

Choose from wire table, nearest oa wire size less than 0.738mm.
Choose 0.706mm oa for wire Cu dia = 0.60mm.

If this oa dia is much less than the maximum allowable section height, sec winding resistance will be too high.

Can more than one layer be used per section?

Possibility 2. There are two layers for each Sec section, each layer having 84 turns and height = 0.706mm, giving total height =
2 x 0.706mm, plus 0.05mm insulation between each layer = 1.462mm.

Is this height more than allowable Sec section height?

In this case the the possible sec section height of 1.462mm exceeds the allowable height of 1.39mm by 0.072mm.

List the total height of all so far calculated :-
Primary wire, 16 x 0.414mm = 6.62mm,
Secondary wire, 8 x 0.706mm = 5.65mm,
p-p insulation = 9 x 0.05mm = 0.45mm,
anode p to cathode p ins = 2 x 0.5mm = 1.0mm
P to S ins = 8 x 0.5 mm = 4.0mm,

S to S ins = 4 x 0.05mm = 0.2mm.
Cover ins over completed winding = 1 x 0.2mm

Sub-Total height = 18.12mm

NOTE. This total exceeds the theoretical maximum available bobbin winding height of 17.6mm by 0.52mm.

This indicates the design would be difficult to wind and fit all wanted layers of wire and insulation within the bobbin height.

Larger alternatives to the OPT-1ATS core size should be explored.

Option 1. Completely revise the whole design starting with a larger core T size = 51mm.
The wanted Afe will be the same as in Step 14 = 2,547sq.mm,
so S = 2,547 / 51= 51mm approximately.
Afe will then be 51 x 51 = 2,601 sq.mm.
Np may remain the same oa dia size = 0.414mm, giving 168 turns per layer across Bww = 72mm.
No of P layers may = 14, giving Np = 14 x 169 = **2,352 turns total Np**.
12 primary layers are in anode to anode circuit with 2 layers in cathode to cathode winding, giving CFB = 14.3%, between 10% and 20% so OK.
Available bobbin winding height = 0.8 x window H = 0.8 x 25mm = 20mm.

Fig 27 below shows OPT-1BTS, and different design which is the Option 1 described :-

Fig 27.

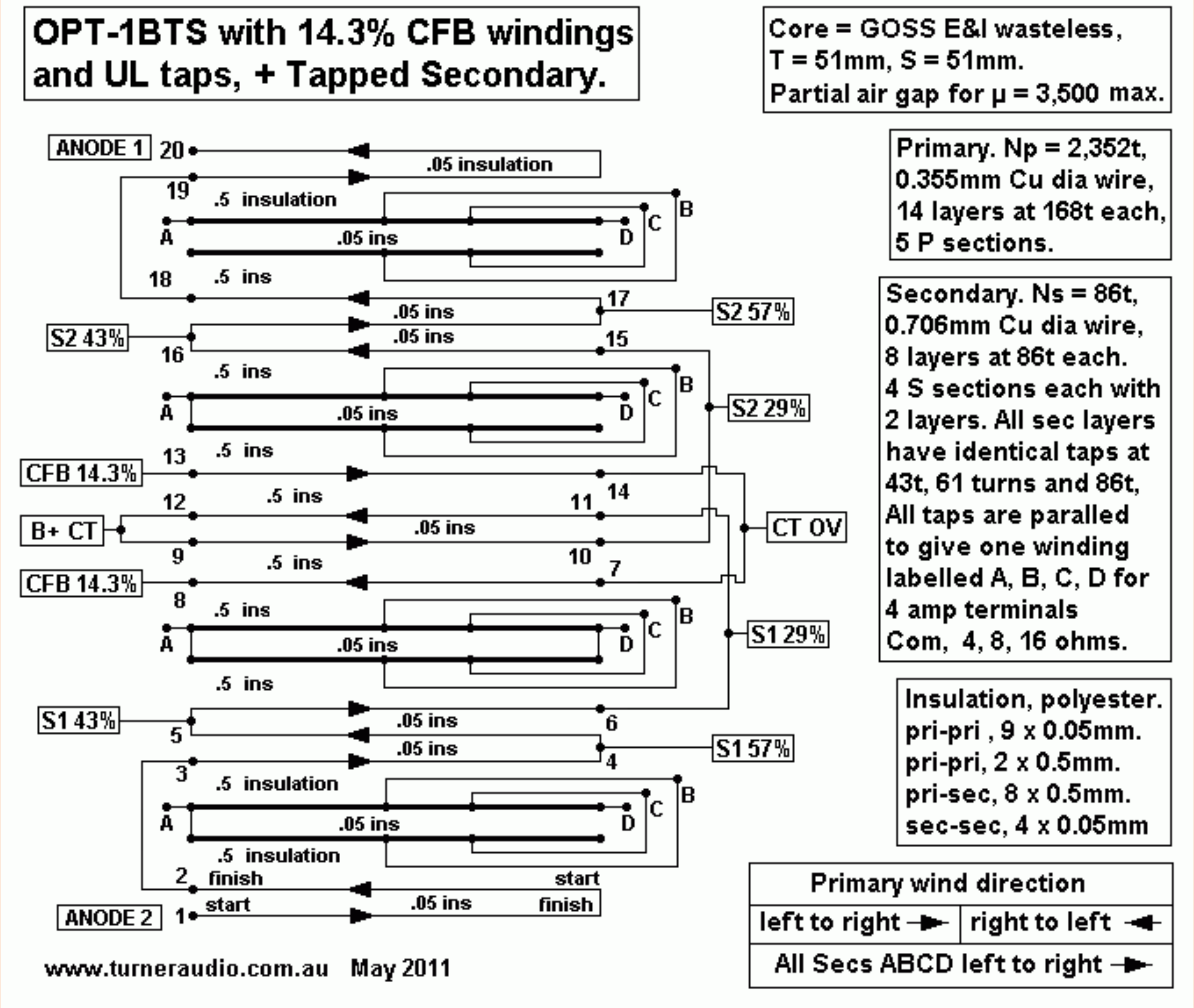


Fig 27 with OPT-1BTS has 14 primary layers in 5 sections and with a variety of screen taps for UL screen grid connection if desired. Ordinary CFB may be chosen with a fixed Eg2, or a combination of UL screen taps and CFB.

Conclusion.

The use of the larger T core = 51mm gives a window size 25mm x 75mm, and so there is more room for windings and insulation.

For OPT-1BTS, Height of all bobbin contents :-
Primary wire, 14 x 0.414mm = 5.80mm,
Secondary wire, 8 x 0.832mm = 6.66mm,
p-p insulation = 7 x 0.05mm = 0.35mm,
anode p to cathode p ins = 2 x 0.5mm = 1.0mm
P to S ins = 8 x 0.5 mm = 4.0mm,
S to S ins = 4 x 0.05mm = 0.2mm.

Cover ins over completed winding = 1 x 0.2mm

Sub-Total height = 18.01mm.

Allowable height of winding = 0.8 x H = 0.8 x 25mm = 20mm.

Total height of bobbin contents is less than allowable, by 1.99mm, OK.

Option 2. Abandon the use of CFB windings and use only the UL connection.

Conclusion. This will reduce the total number of thicknesses of 0.5mm thick insulation from 10 to 8, but increase the total number of thickneses of 0.05mm by 2, thus gaining more height = 0.9mm, and reducing the total height of all bobbin contents from 18.12mm to 17.22mm which is less than 17.6mm of total maximum allowed height.

Option 3. Reduce all 0.5mm insulation to 0.45mm. This will give oa height of 17.67mm, close enough to 17.6mm allowable.

Option 4. Do nothing to change calculations so far.
If the base thickness of the bobbin plus core clearance = 2.5mm,
then total height in window = 18.12mm + 2.5mm = 20.62mm,
leaving a spare 1.38mm. If the excess over allowable winding height is less than 3%, **then careful cramping of completed windings using G-clamp and wood blocks may be used for 2 days until epoxy varnish applied during winding hardens so that wire bulge during winding is removed permanently** and allows easy installation of E&I laminations.

Fig 28 below shows bobbin details for OPT-1ATS with primary with various UL screen taps and without CFB windings, to allow the windings to fit more easily into the bobbin.

With all designs with a tight fit of bobbin contents, the home constructor with little experience or practice will struggle to complete a project.

It is always better to use a design with some bobbin room to spare.

Fig 28.

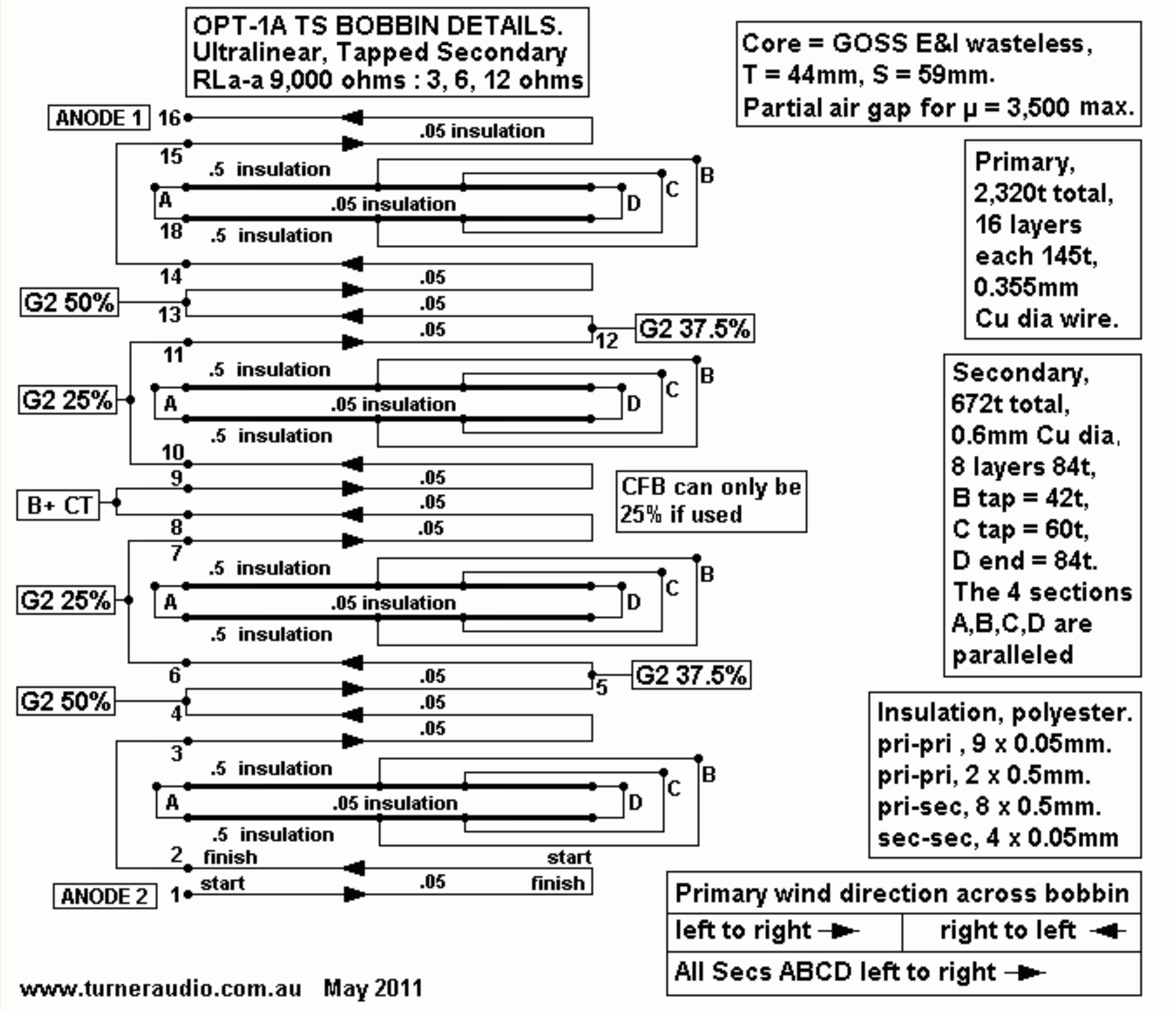


Fig 28 shows the winding layout for OPT-1A TS for a tapped secondary.

Notice that there is a lot more work to wind the secondaries compared to the wasteless winding method for OPT-1A.

51. Calculate Total winding losses, Middle RLa-a.

OPT-1ATS. Calculate all losses considering 6.0 ohms using Ns = 60turns, Np = 2,320t, ZR = 1,495 : 1, Load ratio = 9k0 : 6 ohms.

Primary resistance, from Step 26 for OPT-1A, RwP = 114 ohms.

Primary loss % = 100% x 114 / 9,144 = 1.25%

Secondary resistance =
Rws = 2.26 x (Ns x TL) / (No//S x 100,000 x Sdia x Sdia) ohms,

where Ns = secondary turns, TL = turn length in mm,
No//S = number of parallel
secondary windings, 2.26 and 100,000 are constants,
and Sdia is the copper dia of wire.

OPT-1ATS, Rws for 8 // 60t secondary configuration.
Rws = 2.26 x 60 x 275 / (8 x 100,000 x 0.6 x 0.6) = 0.129 ohms.

Secondary loss% = 100% x 0.129 / 6.129 = 2.1%

OPT-1ATS Table of all Total winding resistance losses, tapped secondary.

Total loss% = P loss + S loss = 1.25% + 2.1% = 3.55%

Is this total loss less than 7%?

Loss% is 3.55%, and OK.

NOTE. The loss % will not be constant for different loads used for various taps. If 3.0 ohms is used with Ns = 60t, RLa-a becomes 4k5. The RwS and RwP will remain constant and losses with 3.0 ohms will double. If 12 ohms is used with Ns = 60t, the losses will halve.

52. Compare winding losses, Tapped and Wasteless Secs.

OPT-1ATS, from Step 50, 9k0 : 6 ohms, Total wind losses = 3.55%.

OPT-1A, from Step 38, 9ko : 6 ohms Total wind losses = 2.55%.

Conclusions.
1. Tapped secs will always have higher winding losses than wasteless windings.

2. Tapped secs always involve a higher number of total sec turns and thus be more difficult and give higher labour time and cost over the wasteless method.

3. With regard to OPT-1ATS, the home DIY person may never ever use speakers with nominal Z above 8 ohms, then turns per layer could be reduced to 60t, and wire size will be 0.9mm Cu dia. Only one layer per sec section would be used so the total Sec turns will be similar to the wastless pattern OPT-1A.

4. The OPT ratio is then 9k0 : 6 ohms which will suit all speakers above 5 ohms. Speakers above 8 ohms, say 16 ohms, tend to be old types and very sensitive, eg, Tannoy dual concentrics made in 1960s, 1970s, and very little power is needed.

5. Therefore there may need to be only 1 tap point for 3 ohms at 42 turns. This will be fine for all speakers above 2.5 ohms. The two taps should suit 95% of listeners.

6. The 60t sec TS winding losses for the 9k0 : 3ohms will be probably be twice the wasteless method, but still less than 7%, and acceptable.

53. Compare LL, Tapped Secs to Wasteless Secs.

Leakage inductance.
The leakage inductance formula :-

$$\textbf{LL} = \frac{0.417 \times Np \text{ squared} \times TL \times [\,(2 \times n \times c) + a\,]}{1{,}000{,}000{,}000 \times n \text{ squared} \times b}$$

Where LL = leakage inductance, in Henrys,
0.417 is a constant for all equations to work,
Np = primary turns,
TL = average turn length around bobbin,
2 is a constant, since there is an area at each end of a layer where leakage occurs,
n = number of dielectrics, ie, the junctions between layers of P and S windings,
c = the dielectric gap, ie, the distance between the copper wire surfaces in P and S windings,
a = height of the finished winding in the bobbin,
b = the traverse width of the winding across the bobbin.

The LL for Tapped Sec will be the same as for Wasteless Sec where the TS uses the whole secondary layer of turns. LL increases when the traverse width or bobbin winding width is reduced for **both P and S windings.** Reducing b to half the value would double the LL.
But with Tapped Secs, where there is a tap along the secondary, only the traverse width of the secondary is reduced. This traverse width is considered to be only the current carrying portion of the tapped layer of turns, and turns not carrying current have no magnetic influence on LL. The largest increase in LL occurs when the least number of secondary turns are used, but the actual increase in LL is not linear to the secondary effective traverse width.
One might assume the effective value of 'b' used in the LL equation = Bww x sq.root of (Sec winding turns / turns for whole layer width).

Suppose in OPT-ATS or OPT-BTS there are 84 turns for one whole S layer, and taps are at 60t and 42 turns.
Where the 60 turn tap occurs,
b = 62mm x sq.rt(60 / 84) = 52.4mm.
LL increases by a factor of 1.22.
In OPT-1ATS, consider the 24turns between 8ohm and 16 ohm terminals.
b will be 62 x sq.rt (24 / 84) = 33.1mm.
LL increases by a factor of 1.87.
Between the 8 and 4 taps there is only 18t,
and effective b = 62 x sq.rt (18 / 84) = 28.7mm.
LL increases by factor = 2.16.

If the sec = 1 turn, then by this reasoning the b
= 62 x sq.rt (1 / 84) = 6.8mm.
LL is increased by factor = 9.16.

I am not at all aware of the accuracy of the above reasoning because I've never ever found any text book explanations on the subject, and had I found something by better scholars than myself, the maths would probably be incomprehensible and ther'd be no practical applications or detailed lab results with no lies.
I have not done enough comprehensive tests on leakage inductance of OPT with tapped secondaries which comply to my interleaving methods here.
I am not aware of any manufacturer who has gone to the trouble of using my method shown here, because exactly what any manufacturer may have done is concealed from view, and they rarely ever disclose their secret information about their OPT which is then subject to the glare of public scrutiny. And then the quality of what they have done may be found to have serious technical shortcomings to best suit the wishes of the company accountant and the shareholders, but never the buyers.

The only manufacturer I know whose OPT had a tapped secondary and which functioned to give width bandwidth and with HF stability while using the "8" to "16" connection is Dynaco. I found this out while entirely re-wiring two Mark-VI mono amps capable of 100W from 4 x 6550 in UL mode and made in about 1960.
The amp owner had 4 ohm speakers and when used with the 8 to 16 connection the turn ration and thus impedance ratio is the higher than id the Com-4 connection is used. Thus all power is pure class A. The owner tried the 8 to 16 connection and found the 30 watts maximum available was plenty, and he spent 10 minutes explaining to me how the sound was just the best he'd ever ever heard. His wife then spent 15 minutes explaining what she heard, and why they were so happy to spend a couple of grand for me to totally

re-construct these amps.
My measurements of the bandwidth with the 8 to 16 connection showed that 40kHz was available, THD was extremely low, and damping factor well above 10, even with the inevitably higher winding losses.

Most manufacturers would not use TWO layers of sec wire in each Sec section as I have shown. They might use single layer secs, so sec winding losses would at least be double what I have tabled above.
Many manufacturers may make the tapped secondary from using 3 sections of secondary, each with 1/3 of the turns for 16 ohms, then simply have a tap for 7.18 ohms at the end of 2 layers, and a CT along the 2nd layer up from the bottom for the 4 ohm connection. This reduces the number of Secondary sections drastically and gives the large increase in LL which I have so often seen in the terrible OPTs which many makers have foisted onto the public who are denied the quality they think they have paid for.

The tapped secondary method of terminating secondary windings has become almost universal for most amplifier makers because 99% of amp owners are quite incapable and unwilling to ever understand the most basic idea about electronics or perform any other technical task other than plugging in a speaker cable, turning on a mains switch and using a volume control.

And they are very likely to plug a speaker cable into the wrong set of terminals if there are more than 2 provided. It matters not how simple one makes it for an owner to operate his gear, some will cook speakers and amps like sausages at a barbecue.

54. Shunt Capacitance with tapped Secondaries.

If the general winding geometry of the interleaving used for Wasteless Windings or Tapped Secondary is the same, the shunt capacitance will remain identical because the capacitances between primary layers to earthy secondaries with low signal voltages remains the same whether or not there is current flow in all or part of the secondary turns.
If the method I have given here is followed, Shunt Capacitance will be low enough to permit wide bandwidth and stablity.

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