The 6C33c-b and the beauty of the low anode resistance audio valves.

By Ari Polisois.

Foreword.

After you read the present article, I suggest you examine the lecture linked to the style SC-SCC output transformers, in the “Products” section of this site.

There, you will find more information on how the two novel types of OPTs, the Self-compensated (SC) and the Split Core - Stereo Common Circuit (SC-SCC), work and what their limits, as well as advantages, are. Kindly note that the concepts, in the present paper, refer mainly to the Single Ended amplifiers’ layout.

The Lo-anode-res-valves.

The Queen of these valves is, by far, the 6C33C-B, the Russian tough and generous triode whose internal resistance can go as low as 80 (eighty) ohms.

But in the western production range, there are also some remarkable types, such as the 6AS7, 6336, 6080, and several others, all designed to be used in voltage or current stabilizing applications. The average internal resistance of these valves is 300 ohms per section, but all of them are double triodes, so the resulting resistance, when paralleled, is one half, that is 150 ohms, which is not bad.

Why do I consider this kind very precious, is what I will explain in the text.

When I retired, after many years spent as an export executive, I dedicated my free time to my preferred hobby, namely audio-electronics, starting with a brush-up of my basic knowledge. Morgan Jones and Menno van der Veen’s books (respectively “Valve amplifiers” and “Valve amplifiers from 10 to 100 Watts”) were a fundamental step.

From them and some other sources, I became aware of the importance of the frequency range in the reproduced sound. Menno has dedicated many years of his life to extend the frequency range of his wonderful output transformers and he convinced me in an absolute way.

Why is it important to preserve the frequency range with its rich bouquet of harmonics?

This requires many efforts and a strong will, focused to refuse any avoidable compromise. It also means that we do not have to add anything new to the original sound (relatively original because it is just what we get from a CD and a CD player or a vinyle and its associated peripherals).**[1]**

Is the result worth the effort ? Definitely yes .

As far as we are concerned (valve amplifiers’ designers and builders) it is a must not to deteriorate further the quality of the source‘s output, if we are really aiming at the best possible sound.

In order to achieve this, we must first know where and how the frequency range is affected.

Generally speaking, leakage inductance, low power-handling ability of the output transformer and stray capacitances are responsible of bending the -0 dB straight line that should go, unaffected, from few hertz to several kilohertz.

I will start with the latter cause.

Stray capacitances and their effects on the hi frequency side of the audio range.

Where do these stray capacitances build up ? Everywhere, from the input to the output, including the RCA jacks, the connecting wires and the output transformer.

Any path that shifts the alternate current signal to ground restricts its amplitude. If it is a capacitance, it affects particularly the higher frequencies.**[2] .** The same result appears if the signal is “trapped” by a non productive inductance.

The major capacitances are found between :-

Winding and winding - Winding and core - Layers - Turns.

The capacitances that act in parallel and the leakage inductance in series are both harmful.

Figure 1 shows that a capacitor can be assimilated to a load, whose resistance is part of a voltage divider. The value of this resistance changes with the frequency, as per the formula $Zc = 2\pi fC$, **(Fo)**

where f is the frequency in Hertz, C is the capacity in Farads and Zc the reactance (or ac resistance) expressed in ohms.

In the case of the presence of several capacitors, these can be strictly in parallel or separated by one or more elements, each with its own resistance or reactance. If all capacitances are strictly in parallel, the effect is more pronounced **(see Fig.2)**

Up to very recently, the hi frequency end was estimated good enough at 15 - 20 kHz, considering that the human ears and associated brain system, cannot process sounds exceeding this limit. The new trend is, however, favorable to a much wider frequency range, irrespective of the human hearing capability. Therefore, many audiophiles insist that the original signal must be amplified to its highest extension. Some skeptical experts estimate that this is useless if the CD does not deliver the corresponding range. To this objection comes the answer of those who believe (and I join them) that the latest statement was expressed

bearing in mind the sinusoidal waves, that have nothing to do with music. As a conclusion to this controversy, two choices are left :-

a. The amplifier's curve must be flat from, say, 20 Hz to 20- kHz (as our grandfathers thought), (this is also called the rule of 400000 in reference to the product 20x20000)
   This spectrum is considered to express an excellent tonal balance.
b. The limits must be extended as much as possible, for instance from 10 Hz to 100 kHz. (and we could name it the rule of the million). Indoubtedly, the phase rotations in the audible spectrum of frequencies, in the latter case, will be less important..
   What to say ? If one can succeed to reach the second goal, why shouldn't he?

The decision taken affects an important parameter : the timbre.

A telephone voice or music, whose frequency range is kept below 3 kHz, is far from conveying the same impressions as a hi-end wide frequency range amplifier, such as those used by singers and orchestras.

In addition to the stray capacitances, another factor deteriorates significantly the high frequency range extension : the Leakage inductance of the output transformer. This subject will be dealt with later in the text, in the chapter dedicated to the OPT's construction.

The low frequencies contribution.

If a loss of bass occurs, the sound is "ill" and the overall wave appears to have lost a lot of energy **[3]**.

The presence of a consistent bass range basement supports the soundstage and keeps the listener's attention focused.

The bass contributes to generate satisfaction, whilst the mid range and treble notes define the scene.

Most of the power generated by the output valves is used by the low frequencies. These require heavier magnetic core transformers, heavier loudspeakers and so on.

The sound traffic is composed by different stations and vehicles, that operate and behave in different ways. What matters is to let them transfer to destination every item, without delays or losses.

Possible accidents are caused by the capacitors, that discriminate between high and low frequencies as well as by the most critical component of an amplifier : the output transformer. All the other components have, of course, their specific importance, but their behavior is much more predictable than the OPT's one.

The OPT's task must be backed by the support of suitable output valves, as everybody knows.

The interpretation of this statement is very wide. In the present paper, I will concentrate on few important aspects.

Matching the valves to the output transformer.

It would have been more accurate to say: matching the output transformer to the valves.

It all depends of what you want to achieve.

We have already set a complex goal : very low frequency response and very extended high frequency range.

The valves are what they are, with their average characteristics and tolerances well known, so we rather concentrate our efforts on the OPT.

1. We know that we must reduce the stray capacitance to a minimum, in this critical component.

2, We also know that me must minimize the leakage inductance.
3. Finally, the size of the iron must be large enough to store and give-back the high energy required by the bass range, with some tolerance below the saturation level, to avoid distortion of the sound.

1.1 - **What are the means of reducing the stray capacitance ?**
Here are the requirements to minimize the capacitance:-
1.1.1. - increase the dielectric thickness (that we will designate with the letter "d")
1.1.2. - reduce the winding width (letter "a") **[4]**
1.1.3. - increase the number of layers (xL1...2...3 etc.)
1.1.4. - provide a large potential difference between the windings
1.1.5. - do not bifilar wind
1.1.6. - it is suggested to use a Faraday shield (electrostatic) , but I do not understand why.
Kindly refer to **Fig. 3** , for the stated references.

2.1 - **Leakage inductance.**
The parts of the windings that are not intimately coupled together generate a leakage inductance. This includes a bad winding geometry.
Considering the primary of an audio transformer, the flux set up by it, which, for some reason, does not link its secondary(ies), produces a leakage inductance, due to the corresponding loss of mutual coupling.
How to reduce the leakage inductance ?
Here below the most common ways :-
2.1.1 - Keep the number of turns to a minimum
2.1.2 - Minimize the build of the coil
2.1.3 - Increase the width of the winding
2.1.4 - Reduce the insulation thickness between the windings
2.1.5 - Adopt twin-wire winding (bifilar).
2.1.6 - Interleave the secondary windings with the primary ones.

CONCLUSION #1
At this point, we observe some contradictory advices concerning the ways to minimize the leakage inductance and stray capacitance. The situation is shown in the following table:-

Leakage inductance	**Stray capacitance**
- Minimize turns	- same suggestion
- reduce build of coil, including depth	- the opposite (increase the nbr of layers)
- increase the winding width	- reduce the winding width
- minimize insulation thickness between windings	- the opposite
- use bifilar winding	- the opposite

Regarding the insulation, a solution could be to choose a material with a lower dielectric constant, to reduce the capacitance, without changing the thickness. The other points require a compromise.

The bass range.
The bass range is responsible for the size of the magnetic circuit and vice versa.
In order to understand what to do best, we should examine the formula that calculates the lowest possible bass response at -3dB **[5].**

$$f_{-3L} = (Za * Kb) / 2*\pi*Lp \qquad \textbf{(F1)}$$

Where f-3L is the lowest frequency (Hertz) reached, at -3dB loss , Za is the anode load of the valve, (ohms), Kb is a constant, that considers the mutual action of the internal resistance of the valve and the anode load. This constant is calculated as follows :-

First divide the internal resistance of the valve by the load. You get X.
Then divide X by 1+X and you get Kb.
Finally, Lp is the inductance of the primary, in Henry.
The formula to calculate the inductance is :-

$Lp (Henry) = (4*\pi*N^2*Ac*\mu r) / (Lm*10,000,000)$ **(F2)**

Where N is the number of turns of the primary winding, Ac is the area of the core in square meters, Lm is the length of the magnetic path of the iron core. (meters) and μr is the relative permeability of the core. Regarding the latter parameter, we will consider a low value that represents the departure for a higher permeability taking place at stronger magnetic fields' levels. The figure chosen is 500, and this is good enough for our consideration.
To express a value that corresponds to a real example, besides $\mu r = 500$, we will take a transformer with an area core of 10 sq. cm (0,001 sq.m in the formula) and a magnetic length of 0,4 meters.
If we choose to have a primary of 1000 turns, the inductance will be :-

Lp = (4*3.14*1000*1000*0,001*500) / (0,5*10.000.000) = 1.57 Henry **(F3)**

With the above formulae available, we can draw some consequences.
However, our analysis will be limited to just some of the parameters that we listed in the former paragraphs.
I want to underline how important the internal resistance of a valve is to match most of the requirements set forth above, in order to obtain a significantly extended frequency range, both at the low frequency and at the high frequency ends.
I selected 5 popular valves having different characteristics, as far as the anode resistances and the suggested loads are concerned.
The following table shows their basic characteristics on which we will focus.

Type of Valve	Anode resistance (Ri) ohms	Suggested anode load (Za) ohms (><)	Ri/Za ratio	(Ri/Za) /[1+(Ri/Za)] (<>) = Kb = bass enhancing factor
6C33C-B	80	600	0,133	0,118
6AS7	280	1000	0,280	0,219
300B	700	4500	0,156	0,135
EL34 (triode mode)	1500	5000	0,300	0,230
EL84 (triode mode)	2000	5000	0,400	0,286

(><) by most data sheets
(<>) this factor will be used for the following calculations.

Going now to the formula F1 of the lowest frequency (paragraph "The bass range") , we can calculate the necessary inductance of the primary for a given lowest frequency at -3dB .

Lp = (Za*Kb) / (6,28*f-3L) **(F4)**

Let us take first a low frequency limit of 20 Hz at -3dB . For each of the valves listed above, we would have :-

	Za*Kb=	Lp (Henry)	**????**	Lp2 (Henry)	**?!?!**
6C33C-B	70.80	0.56	189	1.13	268
6SA7	219.00	1.74	333	3.48	471
300B	607.50	4.84	555	9.68	785

EL34	1150.00	9.16	|	764	18.32	1080
EL84	1430.00	11.39	|	852	22.78	1204

CONCLUSION #2 (on the three left columns' figures)
You must have noticed the big differences in the primary's inductances required to reach the low frequency of 20 Hz, according to the internal resistances of the valves, listed in the preceding table.

What the ???? and ?!?! Marks mean ?
The first gives the number of turns that you need for the primary, under the stated conditions, namely : an output transformer with a magnetic core cross section area of 10 sq.cm , a magnetic path length of 40 cm. at a relative permeability of 500, if you want your low -3dB limit to be at about **20 Hz**.
The second gives the primary's number of turns if you want to fix your -3dB limit at **10 Hz** .
This solution is advisable (because the construction of an OPT cannot be absolutely perfect), if we want to have a consistent bass..
Note : To obtain the number of turns**,** I used the formula

N = Square root of (Lp*Lm*10,000,000) / (12.56*Ac*μr) **(F5)**

Derived from formula F2.

MAIN CONCLUSION.
As you can see, the lower the internal resistance of the valves, the lower the number of turns required to obtain a suitable amount of bass. The ratio between the 300B and the 6C33C-B is approx. 3 to 1 (**555** turns against **189** , or **785** turns against **268**). Of course, nothing prevents you, if you want to have even deeper bass, to increase further the number of turns, particularly if you choose the 6c33. You can easily afford that.
Now, going back to the former chapters, we re-discover that, with a reduced number of primary turns, we can satisfy many of the conditions to reach a higher frequency response, still getting a lot of bass.
In my opinion, this makes the Queen 6c33c-b unbeatable.
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[1] Regarding this point, luckily, some sound engineers are able to produce very good quality recordings, whilst others introduce a lot of subjective changes that alter the body and soul of the original work.
[2] A special case should be mentioned here : with the so-called Miller effect, an increase of the initial capacity takes place if there is an amplification circuit where the capacity resides, such as between the plate and grid of a valve. More on the Miller effect can be found in the available literature on the subject.
[3] As an example, the C core ref. AD32 handles 39,4 VA at 50 Hertz and twenty times as much at 1 kHz, meaning that the power handling capability is proportional to the frequency.
In other words, if we had to deal with **high frequencies only**, we could use a much smaller magnetic core.
[4] Remarks : Increasing the winding width reduces proportionally the leakage inductance. Hence, if you measured a leakage inductance of, say, 10 mH, by doubling the winding length you get 5 mH (approx.)
The same rules that apply to the winding's width are also valid for the thickness of the various insulations.
If you are able to reduce the mean length turn of the coil, the reduction of the leakage inductance is also proportional, provided primary and secondary are closely coupled by interleaving.
On the other hand, the number of turns participates with its square, to produce the leakage inductance. Therefore, if you want to get half that value, reduce the number of turns by 30% .

[5] Reference : Menno van der Veen's book "Valve amplifiers from 10 to 100W".
- 3dB is the point where the amplitude (usually referred to the 1kHz level) looses about 30% of its value.

References : Menno van der Veen – mostly from the above book – Elektor Editions
Colonel Wm. T. McLyman - Transformer and Inductor design Handbook – Marcel Dekker Inc. New York. – Basel.

In a coming article, "How to get the most out of an output transformer design."

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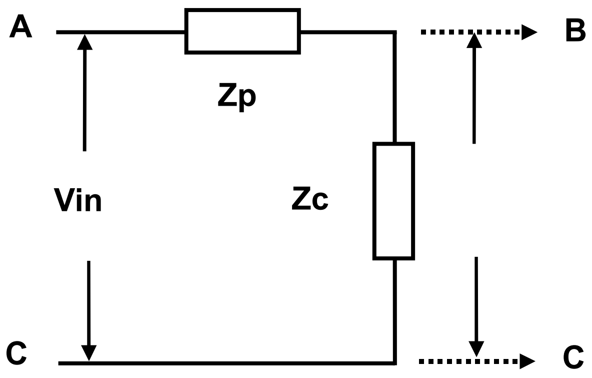
Figure #1 - Leakage inductance representation



Although the capacitance is in parallel with Zp, it can be represented as per the layout on the left

Zp = Impedance of the primary of the OPT (in ohms)
Zc = reactance of the stray capacitance = **1000000/ (2*π*f*C)** ***(μF)***

Example :-
Bearing in mind that a higher stray capacitance produces a lower loss in the primary, we can make the following calculations for a swing voltage of 100% applied to the two reactances:-
Data :-

Stray capacitance of	**0**	μF
High frequency end at	**20000**	Hertz

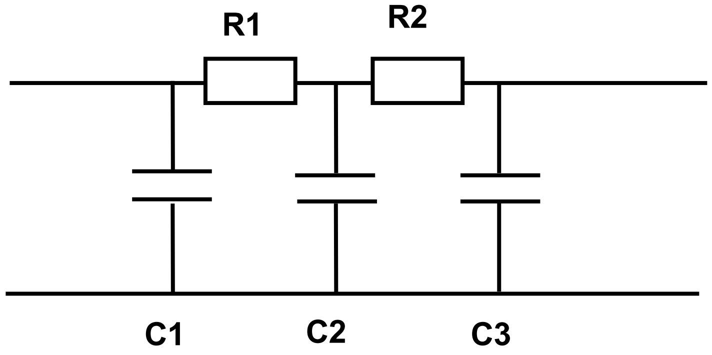
between A and C, we would have a reactance,

at the above stated frequency, of	**9952**	ohms
If the primary's impedance, Zp is	**3600**	ohms
we would get, approximately,	**73**	% of the

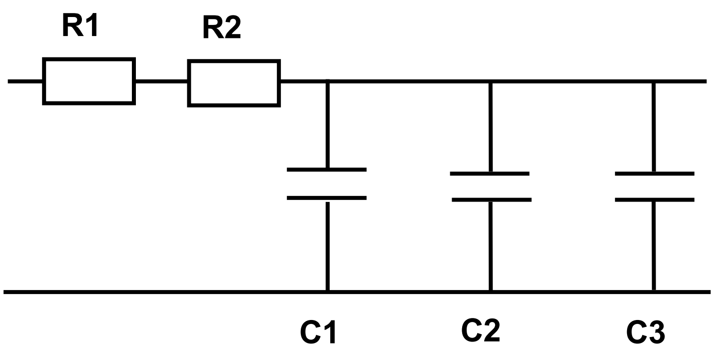
total swing across the primary (induced proportionally to the secondary, not considering other kinds of losses).
This rate is very close to the condition of -3dB (= loss of 30%) generally used to designate the frequency range loss limits.
What if we wanted to reach **100000 Hertz** with the same loss ?
If we repeat the calculation using the frequency of 100.000 Hz, we will find that the stray capacitance should be lower than **200 pF** that is inversely proportional to the frequency ratio.
Is this possible ? Some high quality OPTs can make it and, if we follow the advices contained in this article, we could also succeed.

Figure # 2 - Separated and parallel capacitances.

Case A - Separated capacitances



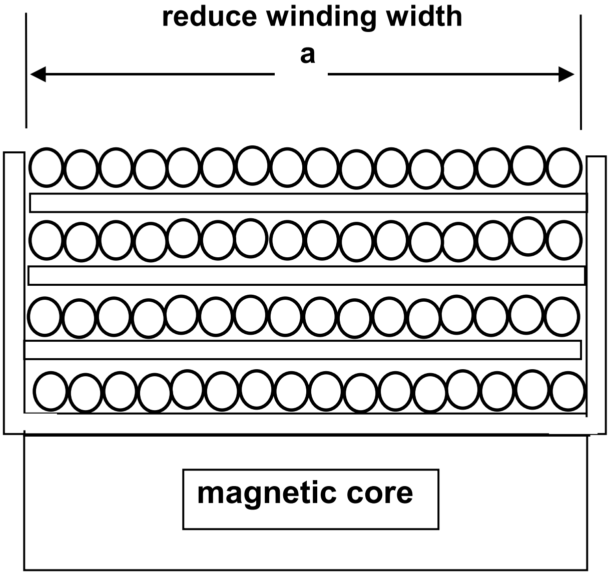
Case B - Cumulated capacitances



R1 - R2 = 1000Ω each **C1 - C2 - C3 = 100 pF each**

R1 and R2 represent the reactances or resistances in the winding.
C1 - C2 and C3 three distributed capacitances.
Case A concens the capacitance between turns. The resulting overall capacity is small, compared to case B, due to the fact that the single capacitances are in series, in the whole winding.
Case B concerns the other kinds of distributed capacitances, such as Winding to core, winding to winding and layer to layer.
The single capacitances can be considered being in parallel and, therefore, the total capacity is their sum.

Figure # 3 - Reducing stray capacitance



xL1 more layers
d thinner insulation material (*)
xL2 more layers
d thinner insulation material
xL3 more layers
d thinner insulation material
xL4 more layers

(*) with suitable insulation properties.
Also : provide a large potential difference between windings, meaning less turns.