## A capacitorless audio amplification stage.

In the present paper, you will find a circuit intended, basically, for single ended amplifiers, that works very well, and uses no capacitors at all, except in the power supplies.
The reason why this important component has been discarded from the circuit, starting from the input and going as far as the output transformer, is that a capacitor is suspected to modify the original sound characters. Many discussions have taken place on the subject, the latest one I read being Menno van der Veen's **(1)** analysis on the distortion introduced by the non-linear behaviour of some capacitors due to the attraction effect of an electrical potential applied to their armatures. When present, a capacitor must be of excellent quality, to prevent all kind of distortions.
Avoiding the use of a capacitor **(2)** implies several sacrifices, but, in return, discloses a number of significant improvements in the reproduction of sound, that becomes, according to many listeners of such amplifiers, "airy, fast and substantial" .
We all know that the perfect audio amplifier does not exist (yet) but, at least, being aware of the degenerations implied in choosing a solution, instead of another, it would be unjustified to accept a bad one.
The list of mistakes that must be avoided is not very long and quite easy to spot. The main ones will be pointed out during the course of the present study. We will start with the capacitor.

**What is the capacitor accused of ?**

First, it behaves differently with low and high frequencies. Its resistance to alternating current varies according to the formula :- $Rc = 10^6 / (2\pi fC)$ , where Rc is the reactance, in ohms (resistance to alternating current), f is the frequency in Hertz, and C the capacity of the component, in micro-Farads.
As an example, between the two conventional frequency limits set for of an audio amplifier (20Hz and 20kHz), the reactance of a 0,22µF capacitor varies from about 36000 to 36 Ohms.
When a signal crosses a capacitor, its reactance participates to the sharing of the voltage of the signal with the other resistances present in the circuit where the relative current circulates.
See for instance a very common circuit (**Fig. # 1a**) used to amplify a signal (in this case with triodes) and transfer it to the grid of the following device.
The values chosen for the components are very recurrent.
*circuit with resistance/capacitor layout.* ||

**Fig.1b** shows the conversion of V1 into a virtual voltage generator, where the internal resistance (Rv1) of the valve V1 is in parallel with the load resistor (Ra1).
The values chosen result in an effective resistance of 9,09 k-ohms.
The signal that builds up across the above generator is transferred to the grid of the following valve, through C1, whose reactance is Rc1.
In **Fig.1c**, with a signal whose frequency is 20k-Hz, the capacitor's resistance (reactance) has been translated into a resistance of 36 ohms. In **Fig. 1d**, the same capacitor is crossed by a signal of 20 Hertz, corresponding to 36 k-ohms. You can read the effective voltage applied to the grid of V2, whose leak resistor (Rg2) is 0,22 k-ohms, a quite common value.

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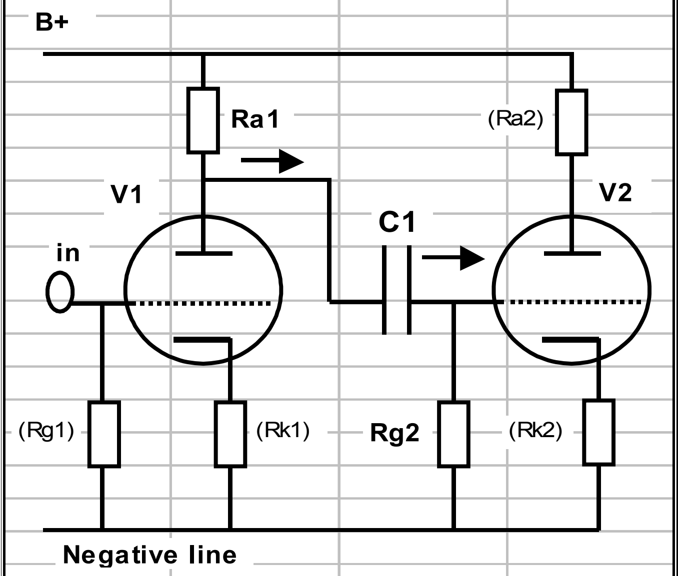
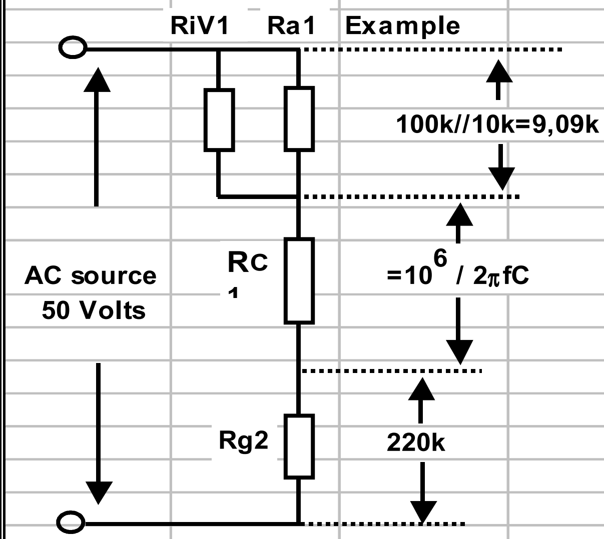
# VOLTAGE DIVISION OF A SET OF RESISTORS AND A CAPACITOR

### Figure 1a

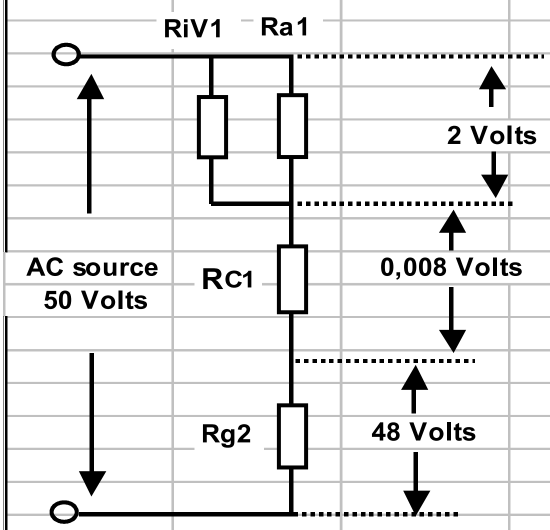



### Figure 1b - values




### Figure 1c

Source frequency : **20 kHz**




### Figure 1d

Source frequency : **20 Hz**

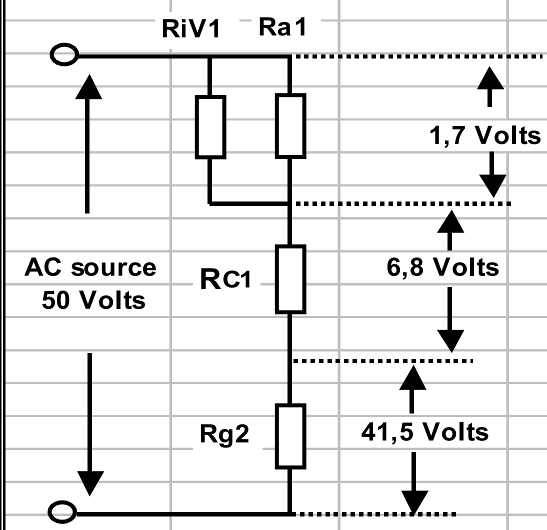


**Table #1** and corresponding graph show the same situation above.
In the first case, V1 receives almost the full signal ( still with a loss of 4% due to the other resistances in the circuit) and in the second a significantly reduced amplitude **(3)**, with a loss of 17%. It is as if you had a volume control that you turn backwards at low frequencies. The result is that the "body" of the sound message, represented by the bass, is weaker and our not Fail to notice it.

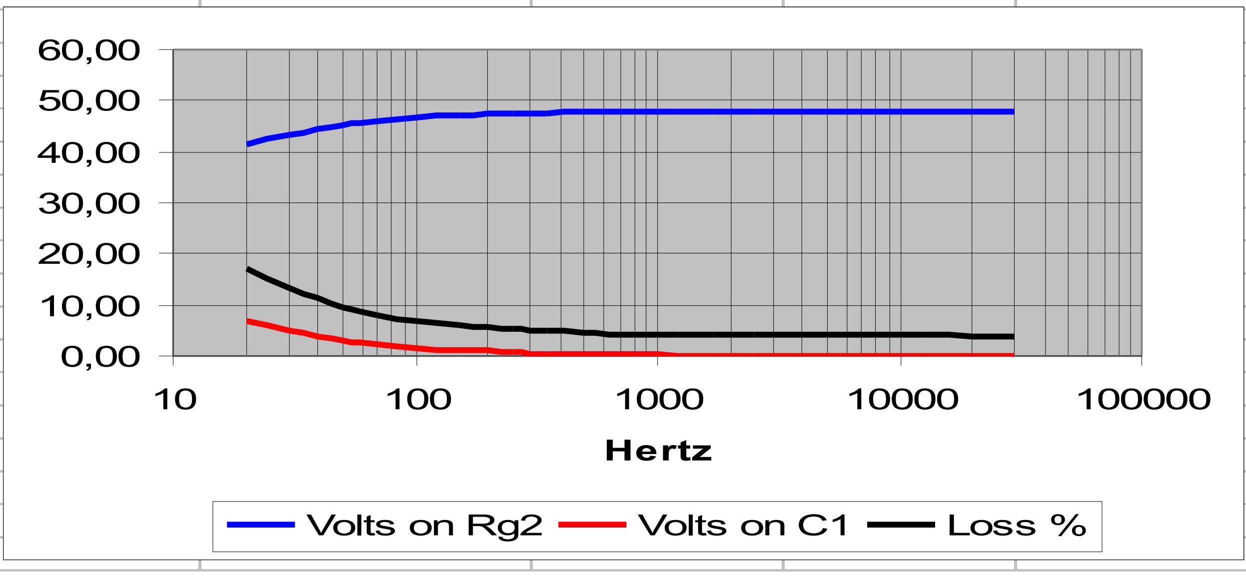
**Importance of the high frequencies.**

As opposed to this feeling, the absence of an extended high frequency range can be compared to listening to the music or voices from another room.
Every fraction of the frequency spectrum is necessary to get closer to realism.
The reduction of the high frequencies' amplitude takes place when there is a capacitance in parallel with the load. In our case, few picofarads connected to the grids or anodes will affect the frequency range. Moreover, due to the Miller effect, the original capacitance value is multiplied by the gain of the valve. You can find easily more information on this subject on the web.
I will add to the above problems another important factor, consisting in the "proportion" of the sounds in relation to each other, in the original message and its reproduction.
This includes, of course, the micro-sounds that most of us are able to hear and that are the source of great psycho-based satisfactions, because they reveal the sensitivity of both partners, the reproduction system and the listener. I suggest you read, on the subject, Menno van der Veen's paper.
Bearing in mind all these goals, we have no other choice but to be very sharp in designing our own circuits and refuse to accept, from the start, without struggling, all kinds of compromises we are aware of. They could make things easier but certainly at the expense of the quality.
The above statements sound very unrealistic, and, in fact, they are, but the purpose of setting such difficult objectives is mainly to prevent us from being too kind and easy going.
We must expect that, during the design of our amplifier we will find a lot of cross points and we will have to choose the direction we believe to be the right one. In spite of some hesitations, we can still find our way to a "satisfactory quality amplifier" from the subjective and objective points of view.
The amplifier described hereafter represents what I personally believe to be a "good one".

**How can we avoid the use of capacitors in the amplifying section?**

Of course, the answer is known : direct coupling.
Many famous amplifiers use this solution. However, only in the Loftin and White's , as far as I know, you do not find any capacitor from the input socket to the output transformer.
Recently, I suggested a circuit, the D.C.M.B. **(4)** that is very similar to the above one, but has what I consider a real advantage (whose benefits cannot be noticed at first sight), a sharp division between the driver and the output stages. This division allows to modify the performance of each stage quite freely and, at the same time, control the interaction between stages. You will have evidence of this advantage by examining the schematics and remarks.

| | TABLE AND GRAPH: # 1 | | | |
|---|---|---|---|---|
| | VOLTS ACROSS Rg2 AND % LOSS | | | |
| Ra1 = 100k | RiV1 = 10k | C1 = 0,22µf | Rg2 = 220k | Vgen = 50V |
| Hertz | V | V | % | ohms |
| Frequency | Volts on Rg2 | Volts on C1 | Loss % | **Reactance of C1** |
| 20 | 41,47 | 6,821 | 17,1 | 36190 |
| 30 | 43,44 | 4,764 | 13,1 | 24127 |
| 50 | 45,16 | 2,972 | 9,7 | 14476 |
| 70 | 45,94 | 2,159 | 8,1 | 10340 |
| 100 | 46,55 | 1,531 | 6,9 | 7238 |
| 150 | 47,03 | 1,031 | 5,9 | 4825 |
| 250 | 47,42 | 0,624 | 5,2 | 2895 |
| 350 | 47,59 | 0,447 | 4,8 | 2068 |
| 500 | 47,71 | 0,314 | 4,6 | 1448 |
| 800 | 47,83 | 0,197 | 4,3 | 905 |
| 1200 | 47,89 | 0,131 | 4,2 | 603 |
| 1700 | 47,93 | 0,093 | 4,1 | 426 |
| 2500 | 47,96 | 0,063 | 4,1 | 290 |
| 4000 | 47,98 | 0,039 | 4,0 | 181 |
| 6000 | 47,99 | 0,026 | 4,0 | 121 |
| 9000 | 48,00 | 0,018 | 4,0 | 80 |
| 13000 | 48,00 | 0,012 | 4,0 | 56 |
| 20000 | 48,01 | 0,008 | 4,0 | 36 |
| 30000 | 48,01 | 0,005 | 4,0 | 24 |



**The schematics.**

**Figure #2** shows a simple but efficient and quality oriented amplifier circuit.
The term efficient is meant in the sense that it uses as few components as possible.
The philosophy is clear : whatever is simple is easier.
For easy reference, the resistors refer to their connections with the valves : Rk1 is the cathode resistor of V1, Rk2 the cathode resistor of V2, Ra1 the anode resistor of V1, etc.
The first and second voltage amplifying stages, based on V1 and V2, use the classic direct current coupling. Their purpose is to amplify the weak input signal coming, for instance, from a CDP (Compact Disk player), that seldom exceeds 1V, and obtain a stronger wave, that must have the amplitude required by V3 (the power valve) to reach full power.
Usually, the peak value of this signal must be equal to the bias level of the power valve, less a couple of volts (to avoid driving the grid positive, and generate distortion ).
Thus, if, for instance, we have to drive a 2A3, whose bias setting is generally –45 Volts, the driver has to deliver a signal whose peak is 43-44V, equal to approx. 31 Volts RMS (root mean square). Therefore, the driver section must be able to amplify the low level signal of, say, 0,7V rms, by 31/0,7 = 44 times. In the schematic of Fig.#2, a 6SN7GT valve is used and its first section (V1), alone, is able to deliver easily 8 to 9 Volts with the above low 0,7V signal input.
As a consequence, if we want to reach an overall 31V driving amplitude, V2 must be able to contribute with a further gain of 3,65 times ( 8,5 x 3,6 = 31 )
We will consider two alternative groups of valves that we will design as Category 1 and Category 2. The first includes the valve types that require a negative bias of about 50V or less, the second, over 50 Volts. More on the requirements of these different levels of bias will be dealt with later in the text. For the time being I will explain how the Direct Coupling Modulated Bias circuit works.

**The main features.**

What is somewhat peculiar in this circuit is the presence of Rx, whose purpose will be fully explained later. Basically, it supplies an extra current to the cathode resistor Rk2. In the schematics, you will notice that :-
a) there are two separate power supplies (see **Fig.#3** and **Table#2** for details), one for the power stage and one for the driver stage, stacked. The negative line of the driver's stage power supply is connected to the general ground, whereas the negative line of the power stage DC supply is connected to the positive line of the driver stage's power supply. This layout results in two distinct direct current paths, independent from each other, which is very important, in our case.
The current circulating in the upper circuit (I will briefly call these circuits "the circles") does not interfere with the one of the lower circuit and vice-versa.
b) There is however a point indirect) in common with the two circles: Ra2.
In the drawing of **Fig.#4**, said resistor has been turned, with its wiring, 180° anticlockwise, to better evidence the connection between the driver valve and the power valve control electrodes (grid-cathode). To enhance the situation, Rg2 ( a small value, 220 to 1000 ohms resistor whose task is to prevent unwanted oscillations) has been omitted.
It is easy to notice that Ra2 is **strictly** in parallel with the grid/cathode electrodes of the output valve. **Anything** that happens to Ra2 is instantly seen by V3's grid/cathode pair, to its full extent. This means that even a slight variation in the electric level of Ra2 ( such as 0,00001V), can be noticed by V3. Menno van der Veen underlined the importance of the microsignals and they could not be treated in a better way **(5).**
c) Some more features, thar are not included here, are offered the D.C.M.B. **(6)** .

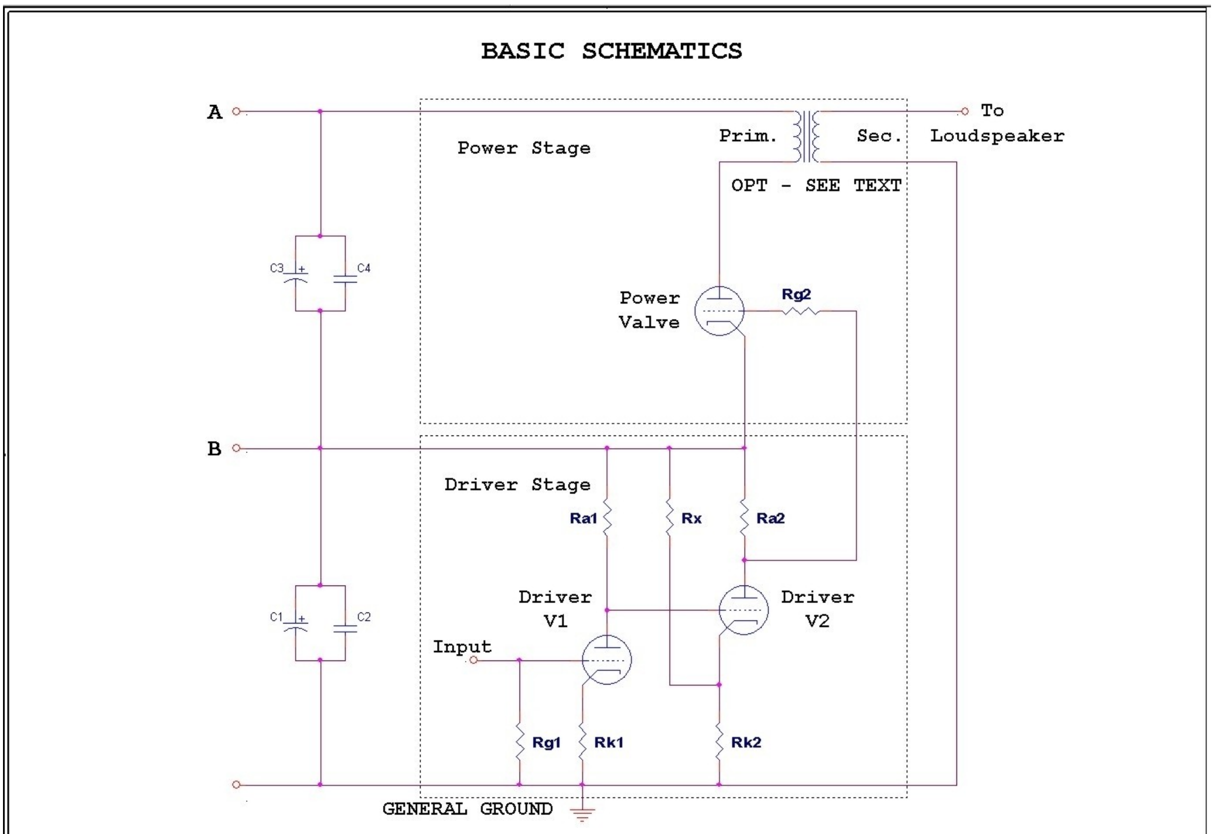

BASIC SCHEMATICS
A
To
Prim.
Sec.
Loudspeaker
Power Stage
OPT - SEE TEXT
C3
C4
Power
Valve
Rg2
B
Driver Stage
Ra1
Rx
Ra2
Driver
V1
Driver
V2
C1
C2
Input
Rg1
Rk1
Rk2
GENERAL GROUND

Fig. #2

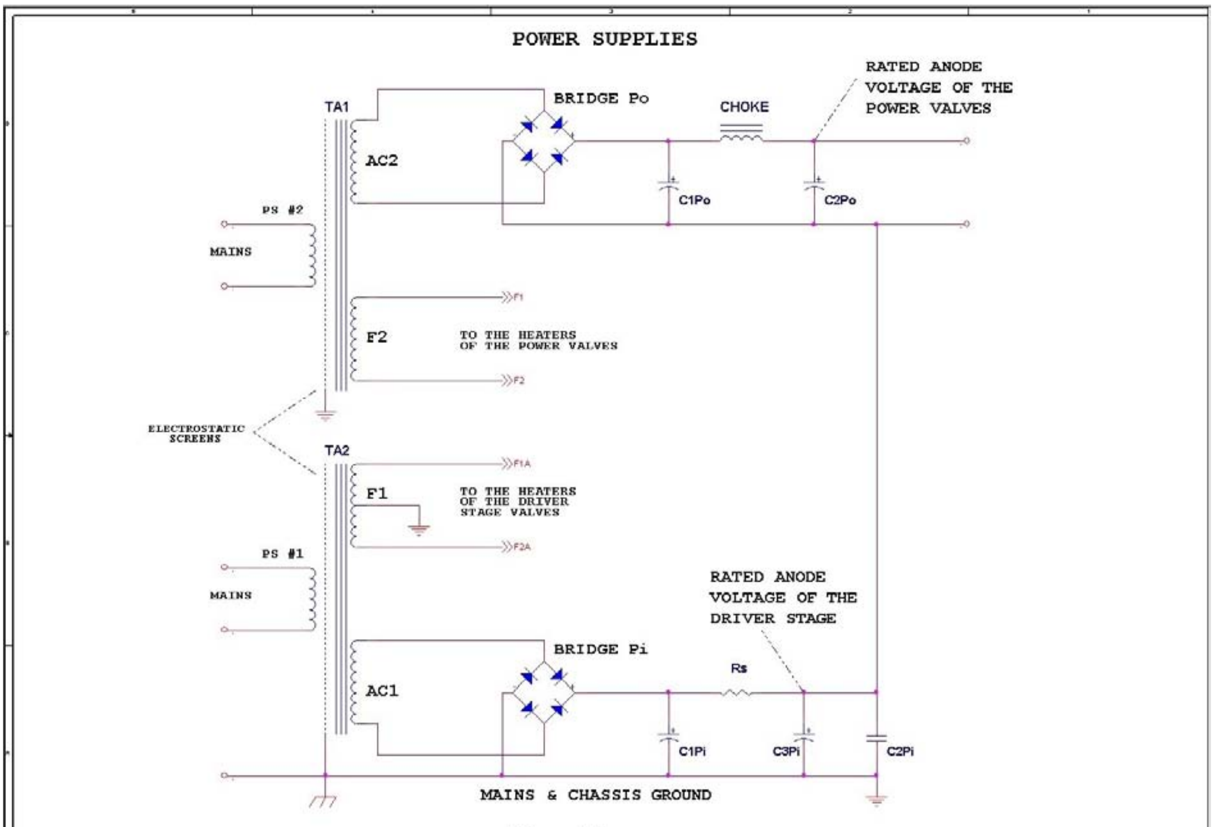

POWER SUPPLIES
RATED ANODE
VOLTAGE OF THE
POWER VALVES
TA1
BRIDGE Po
CHOKE
AC2
C1Po
C2Po
PS #2
MAINS
F2
TO THE HEATERS
OF THE POWER VALVES
ELECTROSTATIC
SCREENS
TA2
F1
TO THE HEATERS
OF THE DRIVER
STAGE VALVES
PS #1
MAINS
RATED ANODE
VOLTAGE OF THE
DRIVER STAGE
BRIDGE Pi
Rs
AC1
C1Pi
C3Pi
C2Pi
MAINS & CHASSIS GROUND

Fig. #3

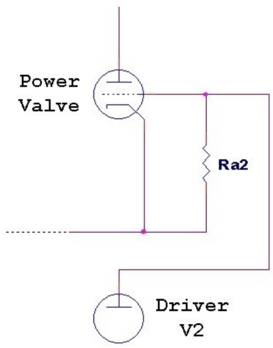



Fig.#4

**For the practical audio amateur.**

Before I proceed with additional explanations, I would like to tell the readers who simply want to build an amplifier with the above characteristics, but without wasting too much time in theoretical details, that they can certainly proceed safely just by following the instructions, provided, of course, they have the necessary experience. This implies, particularly, being fully aware of the dangers in building and handling valve amplifiers, that operate with high and dangerous voltages.

Many will be tempted to make changes to the schematics, according to their ideas, and I am not discouraging them. However, please note that I have spent a lot of time in attempts to optimise the behaviour of the amplifiers I have designed. Recently, I have even built what I named a “Driver performance simulator” . It is not a software, as you can see from **photo #1.**

With this gear, coupled to a variable voltage DC supply (see also **photos #2 and 3**), I can modify, quickly, the values of Ra1, Rk1, Ra2, Rk2, measure them and their voltage, as well as the gain and distortion. The results are fantastic and, what is important, are based on the real characteristics of the valves selected for the purpose. At the same time that I am trying to find, practically, the best solutions, a friend of mine, Eng. Pierre Touzelet **(7)**, an audiophile with a handfull of mathematic knowledge, checks the results with his custom made software. The conclusions match within a small tolerance.

**Let’s do the work !**

Now, what power do you need ? What kind of valves you intend to use?

As you expect, the values of the components have to be adjusted accordingly.

Regarding the driver valves, I strongly advise to use the 6SN7GT (many brands are still available) or similar (ECC82/12AU7 and others) because they perfectly comply with the requirements. The first triode ( V1 ) is almost universal for a wide variety of cases. The following stage of the driver (V2) must be adapted, case by case, with suitable value components, the choice of which is more complex, unlike with V1. I anticipate that, when it comes to very high swings, it is necessary to put the two triodes of a 6SN7 in parallel, as will be seen after reading the following chapters. For your knowledge, with the latter solution, I reached, with a 6SN7GT, to following results, needed for an 845 tube amplifier under construction:-

Ra1 = 220k/2W    Rk1 = variable from 900 to 1200 **Ω**/ 1/4W    Rg1 = 220k to 1 Meg.
Ra2 = 11k/4W    Rk2 = 1200 **Ω**/25W    Rg2 = 220**Ω/1/4**W    Rx = 10k/50W
Input = 0,77 V RMS (1,08V peak)    Output = 60 V RMS ( 84V peak)    THD = 0,6%

If I wanted to reach a higher swing (but this one is OK for the purpose), with a higher level input signal, the distortion would increase, but not too much. The DC power supply was set at 350V (but certainly 400V would be better). With the 6SN7GT I have experienced higher B+ voltages, up to 420V, with very good total harmonic distortion rates, but this is not advisable with the ECC82, rated for a maximum of 300V between anode and cathode.

Recently I have built a small and compact amplifier (3 or, alternatively 5W per channel) with an ECC82 in the driver, which is the same either for the 6080 or 6336 output tubes used, that require a bias of –50 and –42V, with a B+ of 130 and 150V respectively, and it worked fine (in spite of the fact that it was somewhat crowded underneath). Please see **Photo #4**.

**Component values and power supply voltage.**

In order not to confuse the reader, I will stick to just one type of driver valve, the 6SN7GT.

As a first step, what influences the following choices is the bias to be applied to the power valve.

In the layout of **Fig.#2**, said bias corresponds to the product Ra2 (ohms) multiplied by the anode current of V2 (Amperes). The latter, in the driver described, varies from 0,005 to 0,006A, and depends, in turn, on the bias and anode voltage at which V2 operates.

V1 can be operated without changing the components' values, for a wide range of applications, as mentioned.

The voltage of V1's anode, to ground, depends on the value of Rk1 and Ra2 and, of course, on the DC level of the power supply. In the DCMB it is important to keep this voltage as low as possible (from 25 to 60V, orientatively), because it will have to be lower than the voltage across Rk2, as we will see later.

How to achieve this ? Supposing we use the highest admissible B+ voltage ( between 350 and 420V for the 6SN7GT and similar valves), Ra1 could be from 180k to 330k. This will ensure a good gain ( 12-15 ) out of the maximum we can get ( the μ of this valve varies from 17 to 20, according to the brands).

As far as Rk1 is concerned, the drop at its terminals, that corresponds to the bias applied to the grid of V1, must be higher than the peak of the input signal, possibly by 30% . Therefore, if we apply a 0,7 rms voltage ( approx. 1V peak) at the input, the DC drop on Rk1 should be 1,3V. Practically, a resistor of 1 to 1,7k is suitable, depending on the value of Ra1 and the B+.

The good side is that you can find out the answer by trial and error, with only V1 active, whilst V2 is not operating (heaters and anode voltages off), until you reach a satisfactory result).

Bear in mind that : the higher Ra1 , the lower the voltage of the anode of V1 to ground (see above). Also, the lower is Rk1, the lower the same voltage above. Understanding this is easy by just studying the valve's behaviour in the common cathode layout.

Suppose now that you have set the anode of V1's voltage to ground to 50V.

You can see in the schematics that this voltage is directly applied to the grid of V2.

If we do not take any steps to reduce this voltage (measured between grid and cathode), V2 will be destroyed in few seconds, because an excessive current will build up (grid and anode).

In fact, V2 is supposed to operate, in still, or idle condition (without signal) at a negative voltage, in the range of –6 to –10V. How to achieve this condition ? Simply by raising the potential of the cathode to ground to 50V (V1's anode potential) **plus** 6 to 10V.
Selecting, for instance, 7V, we get 57 Volts.
We will use the known method of the cathode bias resistor, bearing in mind that we have decided that the anode current of V2 will be 6 mA.
This means that the value of Rk2 must be 57V / 0,006A = 9500 ohms !!
Before commenting this situation, let us first have a look at another parameter : the bias for the power valve. Suppose that this bias has to be applied to a 300B, then it should be approximately -90V. This voltage drop can be achieved by an anode resistor (Ra2) of 15K (90V/0,006A= 15k) and it would not be a problem.
The real problem is that, if V2 operates with Ra2 of 15k and Rk2 of 9k5, with its µ of 17 or 20 it will never be able to contribute with a suitable gain, to reach the peak swing of 85-88 V required to get full power from the 300B.
In order to achieve this goal, we must absolutely reduce the value of Rk2, possibly to 1,5k, but still keep the potential of the cathode at 57V **(8).**
At this point, I call your attention to Rx. Connected between the B+ and the cathode, it brings to the latter the extra current that is necessary to keep the cathode potential at 57V, with respect to ground, but using the above mentioned bias resistor of 1k5, instead of 9,5k. Thus, we can hope to get a satisfactory gain from V2.
A quick check shows that a value of 10k, for Rx, is suitable, as per calculations that follow, with a B+ in the range of of 400V (for different voltages, we will have to make some minor adjustments):-
First we calculate the current flowing in the 10k/50W resistor; it results to be:-
(400-57) / 10000 = 34,3 mA and therefore the drop on Rk2, due to this auxiliary resistor, will be: 34,3 mA x 1500 ohms (suggested value of Rk2) = 51,5V
To this voltage we must add the 9V resulting from V2's regular anode current ( 1k5 x 0,006 = 9V) and we get the voltage of V2's cathode with respect to ground which will be now : 60,5V.
We find that we have exceeded by 3,5 V our goal of 57V, but we can easily correct the situation either by slightly reducing the B+ voltage or by lowering V1's anode voltage. Also by reducing slightly the value of Rk2, but this is somewhat more critical.
By increasing of the value of Rk1, we can reduce the anode current of V2 and, consequently, the potential of Vk2. This, by experience, turned to be the best way and, in the amplifiers I build, I put a variable resistor in parallel with Rk1 (whose initial value should be slightly increased), in order to operate a fine adjustment of V2's anode current. Obviously, when the latter changes, the bias applied to the power valve follows.

**Résumé.**

I apologise if I have spent a lot of words to explain situations that most of you know very well, but this was done thinking of the readers that are attracted by the idea of building their own amplifier and that are newcomers in this fabulous field that gives so many satisfactions.
The explanations given, if well understood, should be sufficient to allow designing an amplifier with the D.C.M.B. topology.
When it will come to the choice of the power valves, please remember that, with the 6SN7GT, it is easier to design a driver unit for a high output valves' bias, rather than for a low one. The reason is that the parameters of this valve (anode current, bias, µ, internal resistance and optimum anode load) are ideal for a reasonable rate of amplification (V1 and V2 can reach 100 times the input signal), and obtain a suitable drop of voltage across the load resistor Ra2, whose suggested average value is 10k (from 8k2 to 15k – less than this will increase

distortion). When optimised, the distortion is very low (less than 1% at full swing). **Table #2** gives some suggestions, based on many experiences during the last years.

If you are fully equipped, use a variable B+ voltage supply and measure the driver's AC output voltage and check, with a distortion analyser, the rate of THD (total harmonic distortion). More modestly, checking, with an oscilloscope, the shape of the sine wave at the output of the driver, enables to evaluate the distortion when clipping takes place.

**How to use the information contained in this paper.**

1) Choose a power valve that you would like to use.
2) Examine and note its characteristics and parameters
3) Follow the recommendations of the data sheets as regards the heater and dc power supplies voltages, as well as the impedance of the output transformer.
4) Knowing the bias normally required for the power tube, choose V2's anode resistor's value (between 8k2 and 15k) and the idle anode current ( for the 6SN7GT the latter can range from 5 to 10mA per valve). The product of these two parameters should correspond to the required bias. Example :-
   **for a 6C33C-B** power tube – bias = -90V
   V2 anode load resistor = 10k ( 4W)
   Anode current of V2 = 9mA ( you will find in the text all suggestions to reach this anode current in the most effective way).
5) Check that the gain of V1 plus V2, with an input voltage of common level (say 1V Peak - approx. 0,7V RMS) corresponds to an output peak voltage, from V2, of 87-88 (power tube bias of 90V less 2-3Volts)
6) Keep in mind that you can run the 6SN7GT with a B+ voltage as high as 420V (but it is wiser not to exceed 400V) and that the higher the voltage, the lower the distortion (within reasonable limits, meaning by reasonable the above mentioned maximum and about 300V minimum). If you choose a B+ of 400V, the voltage between anode and cathode of V2 will be : 400V, less 90V (across Ra2), less about 60V between k2 and ground thus reaching 250V , which is a safe choice for the valve. With regard to the power dissipation, it will also be on the safe side ( 250V x 0,009A = 2,25W against a maximum of 3,5W).

I hope everything is clear and I wish you success.

Ari Polisois
A2Belectronic@wanadoo.fr

(1) Menno van der Veen AES paper 124th Convention – Vienna - Austria

(2) Limited to the audio signal path, obviously, because capacitors are indispensable in the auxiliary circuits of an amplifier.

(3) The comprehensive formula is Rg2 / ( total of resistances in the circuit ) multiplied by the voltage supplied by the generator which, in our case, is the alternating current produced by V1.

(4) Direct Coupling Modulated Bias. More on this subject in the site www.audiodesignguide.com - look for thr banner D.C.M.B. – at almost the end of the list.

(5) We still have the OPT to consider, but this is another matter.

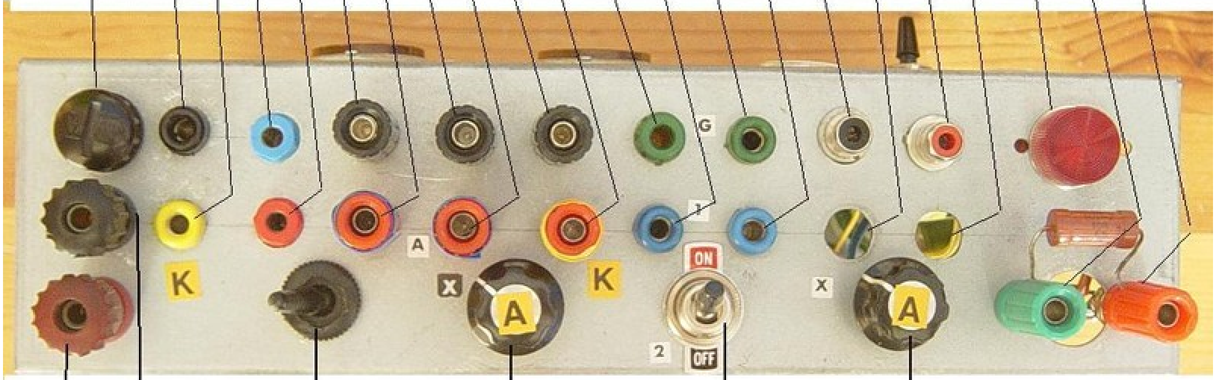
(6) Some can be found in the site above.

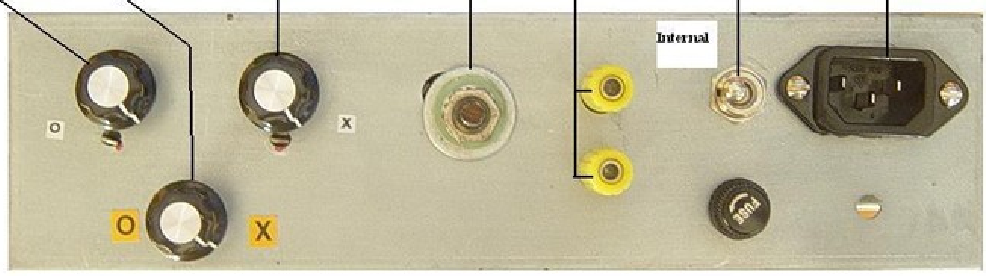
(7) Author of many papers presented at the AES conventions.

(8) We could get a higher gain by by-passing Rk2 with a capacitor of suitable value (in the range of 47 or 100µF) and voltage, but, as we said, we choose to avoid capacitors.

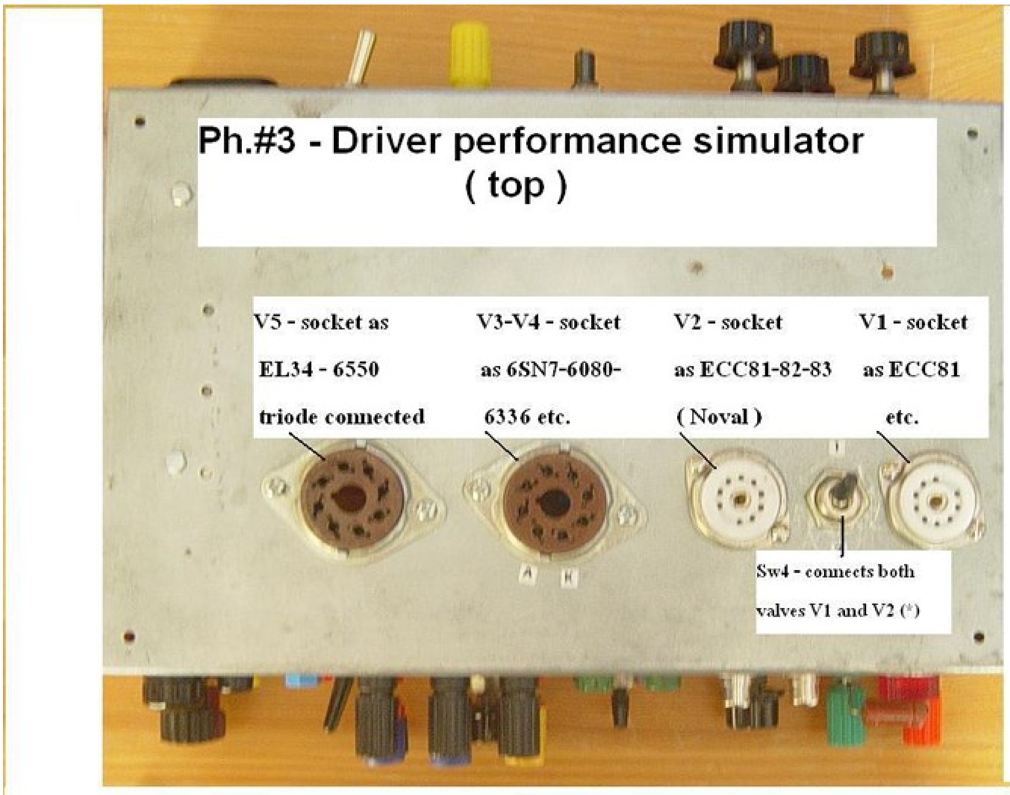
In the present case, an unbypassed cathode resistor applies a negative feed back that reduces the distortion of V2.

## Ph.#1 - Driver performance simulator




## Ph.#2 - Driver performance simulator ( rear )


Ph.#3 - Driver performance simulator
( top )
V5 - socket as
EL34 - 6550
triode connected
V3-V4 - socket
as 6SN7-6080-
6336 etc.
V2 - socket
as ECC81-82-83
( Noval )
V1 - socket
as ECC81
etc.
Sw4 - connects both
valves V1 and V2 (*)