Letter to the Editor

Dear Jan,

While working hard on the 2nd edition of 'How to Gain Gain' I also studied the fix-biased[1] cathodyne (also called Concertina Phase Splitter = CPS) and I went through the whole derivation process to get the gain and output resistance equations. After I've finished my work by accident I stumbled over the cathodyne calculation approach offered by Stuart Yaniger in L|A Vol. 0. Consequently, I also studied the two LTEs from Christopher Paul and Peter van Willenswaard.

To sum-up my findings: Stuart is absolutely right, with the exceptions of the following two points that I may have not understood right:

1. In Fig. 2: the internal resistance of a triode is r_a or r_p and not, as far as I know, $r_a+(1+\mu)R_c$
2. In Fig. 12: the treatment of the grid-anode capacitance $C_{g.a}$ is questionable. Stuart talks about $2*C_{g.a}$. I think that C compensates the anode part of the Miller capacitance = $C_{g.a}$, that is located parallel to R_a, and the anode-cathode capacitance $C_{a.c}$ is located between anode and cathode parallel to the balanced output resistance $R_{o.bal}$, which is NOT the output resistance between anode and ground nor the one between cathode and ground (Christopher's equations 18 and 19).

However, the 'rest' of his story is correct and I very much appreciate Stuart's treatment of the whole matter. For an accurate math simulation of any CPS we need the accurate equations. Because Stuart gave only (the right) rule-of-thumb equations in his Fig. 3 I add the accurate ones here. The whole derivation process can be studied on the attached Mathcad file that is split into four parts. The first one (1.1 and 1.2) derives the equations by application of the well known gain equations of a cathode follower CF with anode load and of a common cathode gain stage CCS with un-bypassed cathode resistance. The second one (3.1 - 3.3) follows the tougher path by Kirchhoff and Ohm with two alternatives on the calculation of the balanced output resistance $R_{o.bal}$. With that it also becomes the proof of the results of the first approach.

The third part (1.3 and 1.4) derives several graphs showing typical output and input behaviours of a CPS, basically calculated with Stuart's component values. A fourth part (2.1 - 2.3) is included for comparison reasons. It shows the gain and output resistances by considering the CPS as un-balanced to un-balanced converter, using the outputs and output loads alternatively and not at the same time!

The CPS is nothing else but an un-balanced to balanced converter. Therefore, the interesting things for the handling of the balanced signal at the output of the CPS and the balanced input of a following (also power) amplifier should be the load resistance R_L dependent gain $G_{bal}(R_L)$ (= balanced output voltage divided by un-balanced input voltage with output loaded by R_L between anode and cathode) and the balanced output resistance $R_{o.bal}$ (= internal resistance between anode and cathode). The equivalent circuit of the CPS is given in Fig. 1. We set $R = R_a = R_c$ and we obtain the following R_L dependent gain $G_{bal}(R_L)$:

[1] The more complex derivation of the self-biased PCS will also be part of the 2nd ed. of HTGG – plus noise calculations, of course.

$$G_{bal}(R_L) = \frac{v_{o.bal}}{v_i} = \frac{2\mu}{2+\mu+r_a\left(\frac{1}{R}+\frac{1}{0.5*R_L}\right)} \qquad (1)$$

With R_L = infinite we get the idle gain $G_{0.bal}$:

$$G_{0.bal} = \frac{2\mu R}{r_a+(2+\mu)R} \qquad (2)$$

With $R>>r_a$, $G_{0.bal}$ becomes roughly the difference of Stuart's Fig. 3 idle gains $\mu/(2+\mu)$- $[-\mu/(2+\mu)] = 2\mu/(2+\mu)$

The balanced output resistance $R_{o.bal}$ thus becomes:

$$R_{o.bal} = \frac{2 R r_a}{r_a+(2+\mu)R} \qquad (3)$$

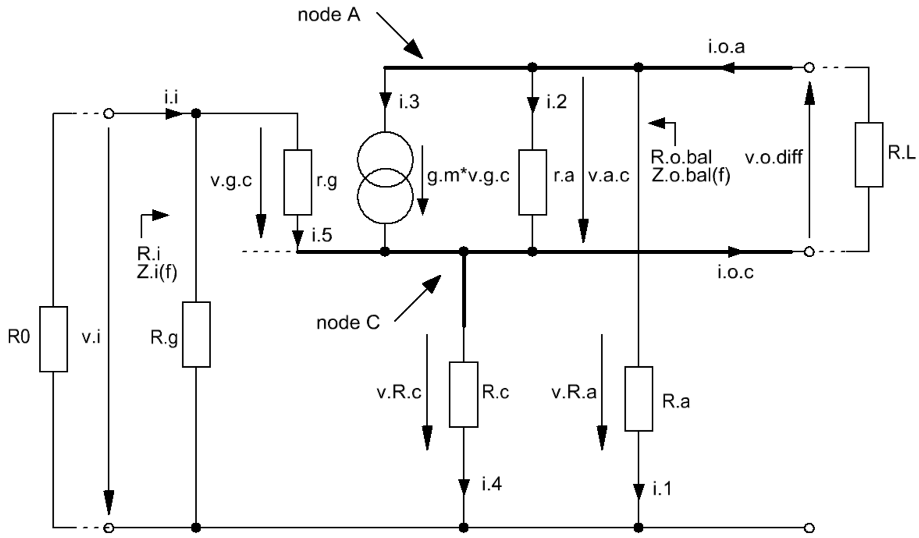

Fig. 1 Equivalent circuit of a CPS
(= Fig. 10.17 on the MCD worksheet)

Fig. 2 shows the simplified equivalent circuit to get the balanced output resistance $R_{o.bal}$ by application of the CPS gain equations (see 1.2 of the MCD worksheet). The sum of Stuart's Fig. 3 rule-of-thumb internal resistances (= $2*(1/g_m)$) equals roughly $R_{o.bal}$.

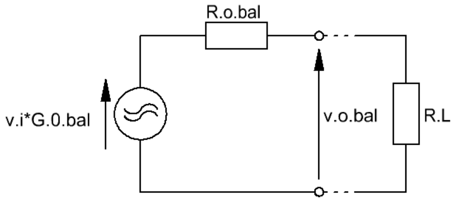

Fig. 2 Simplified equivalent circuit of Fig. 1
(= Fig. 10.10 on the MCD worksheet)

Fig. 3 shows the principal gain stage set-up that includes the triode capacitances that need compensation by $C_{o.c}$ at high frequencies only. Here, $C_{o.bal}$ is the data-sheet given capacitance between anode and cathode $C_{a.c}$.

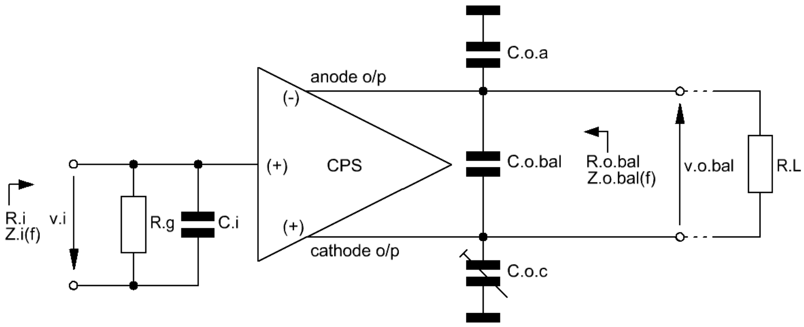

Fig. 3 Principal gain-stage set-up with output capacitances
(= Fig. 10.9 on the attached MCD worksheet)

I think the CPS is a rather perfect replacement of a transformer that has a turns ratio of 1: $G_{bal}(R_L)$, un-balanced in / balanced out. It could be trimmed to 1:1 by e.g. decreasing R and with R_L = 10k and it could very well serve as active balanced output of any pre-amp or phono-amp. Because of its balanced output there is no need to add an additional CF at the CPS's anode that could decrease the un-balanced output resistance at the anode (e.g. the Keppler solution) to a value close to that of the un-balanced cathode output. This is thinking in un-balanced gain and output resistance terms and wrong in a balanced environment. Nevertheless, I agree, that thinking in un-balanced terms is essential when talking about PSRR and CMRR of a balanced situation that is embedded in an un-balanced amplifier environment - which is the case here.

I didn't built-up a CPS yet. It will be one of the winter tasks. Therefore I'm asking Stuart to measure the balanced output voltage across R_L of Fig. 3 with his scope. With his calculation approach via time constant I would be not surprised that he's going to get $R_{o.bal}$ very close to what I've calculated with his component values (rounded 258R7).

In addition, Fig. 4 shows something for the sceptic folks. It's a rather simple looking problem. The task: calculate the resistor values R1 and R2 of a balanced 1st order Butterworth lp with a time constant of 75µs. It is located between the output of Stuart's CPS and the input of another amp with a balanced input resistance of > 30G. Because of other reasons we must use one of the 100nF/ 0.1% capacitors we already have.

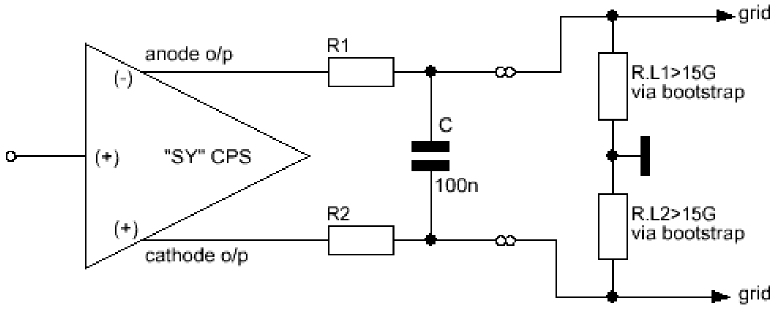

Fig. 4 Balanced lp problem

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Attachment: pdf of an MCD worksheet with 11 pages