Letters to the editor

Dear Editor,

I would like to comment on Stuart Yaniger's analysis of the cathodyne phase splitter in his article in Vol 0 "Split the Difference: The Truth about the Humble Cathodyne". To make my stance clear from the outset: I don't contest that the cathodyne generates equal voltages into equal loads, but I do not accept that the cathodyne's anode and cathode output impedances are of equal value.

The 'law' of equal output impedances that Yaniger deducts presupposes explicitly that the loads be equal - otherwise the proposition would not hold. From all traditional and well-respected triode analyses we know that the anode impedance is relatively high (the exact value depending on whether the external cathode resistor is decoupled or not), and the cathode impedance is rather low (which is the very reason why cathode followers exist). Typically they differ by the triode's amplification factor μ. So how on earth does a triode 'know' that equal loads have been connected to anode and cathode, and then suddenly change its otherwise very different output impedances?
Let's approach it from another angle. Equal loads, okay? Then two loads of infinite value are also equal loads, right? But in that case no one in his right mind would contest that the traditional triode formulas apply, meaning a difference of a factor μ, see above.

But let us follow Yaniger's train of thought. Next to his fig.1 he says: "Kirchhoff's Law forces the voltages across each of the load resistors to be equal, if we assume that the loads at each output are equal." Absolutely right. Look at this fig.1: the current through the triode can go nowhere else but through the total external anode load as well as through the total external cathode load, and if these are equal this current will necessarily induce the same voltages across them. So far so good. But the transformation that leads to fig.3 is debatable. Not in its effect, but in its suggestion. 1/gm now appears as THE output impedance seen when looking into the anode of the cathodyne. While Yaniger is still careful in his opening line of the Source Impedance chapter, caution is lost in the second line: "..... impedances of the cathodyne's cathode and plate outputs are, *they act as if* they are equal under the equal boundary condition. But what IS that impedance?....." (italics mine). Preisman, quoted by Yaniger, never crosses that line, never goes beyond "*apparent* source impedance" (see www.aikenamps.com/cathodyne.pdf).

What we are presented with in fig.3 is certainly the outcome of the Thevenin experiment discussed in the 2nd paragraph next to fig.3, but there is another method to measure impedances and that shows unequal results. This method uses a current-source, and as a current-source because of its intrinsic infinite impedance does not change anything in the load conditions, it therefore does not violate the equal-impedance restriction. Inject a known (small) probing current into an unknown impedance, measure the resulting voltage across that impedance and voltage divided by current will tell you the value of that impedance. Apply this method to the cathodyne's cathode and you will see a low impedance, apply it to the anode and you will see a high impedance. This is a true impedance measurement method, pure, without any preceding conditions. So how does this relate to the much lower *apparent* impedance as experienced with the cathodyne phase-splitter? Well, if you insert the same probing current as used for the anode measurement and inject it simultaneously but in anti-phase into the cathode, then you'll see the lower impedance when looking into the anode. However, if you use the current-source method to measure the cathode's output impedance, you will find a low value *whether or not this probing current is injected into the anode as well!* (In fact there will be a slight difference due to the minor [1/(1+μ)] influence the anode voltage has on the cathode, but the values will typically be not more than 5% apart).

So what is physically happening when a cathodyne phase-splitter provides a perfectly symmetrical driving source for equal loads, resistive as well as capacitive? I said above that a triode cannot see whether its external cathode and anode loads are equal or not. But in a way a cathode can 'see', 'feel' if you like, its external load. The simple case when anode and cathode are only loaded by identical Rp and Rk resistors (as is the standard cathodyne circuit) connecting them to power supply and ground respectively needs no further explanation: the output voltages will be equal (but of course in opposite phase). Now imagine the cathode also becomes loaded by a capacitor C1. This acts like a cathode decoupling, and steeply increases the gain of the triode with increasing frequency: the anode (ac)voltage would go sky-high. This situation changes if a second capacitor C2 is inserted to load the anode: as the anode's impedance is high, the effect of C2 is large and counteracts the effect of the increase in amplification. And if C2=C1, the roll-off created by the anode's resistive impedance and the C2 capacitance fully neutralises the gain increase and the outputs will produce equal voltages. In other words, the extra current imposed on the cathode by C1 protrudes from the anode (there is no other way out, remember) and finds C2 in its path, hence equal voltages if C2=C1. In other words yet: this is a case of feedforward: the cathode senses C1, and tells the anode what to do with C2! It does not work the other way around: connect a capacitive load to the anode only, and hardly anything will change at the cathode side.

Preisman supports the feedforward view in the following paragraph taken from his 1960 article:

"..… impedance for the plate output terminal Ap of Fig. 1 is also as low provided we also accept a lower apparent generated voltage. Or, we can say that the apparent source impedance for this terminal is high-

er, namely {rp + (1 + u)Z}, provided we also specify the higher apparent generated voltage. When Zl=Zk, the individual impedances lose their separate identities, as do also Eqs. (9) and (10), whereupon we can regard either output terminal as having a higher or lower source impedance, provided we also adjust the apparent generated voltages to correspondingly higher or lower values. It is only when we permit Zk and Zl to be unequal that we must use Eqs. (8) and (9) separately rather than use Eq. (11) for both output voltages. We see, therefore, that the paradox is resolved if we take into account not only the change in source impedances but also the change in source-generated voltage. One can compensate for the other, but only in the case where Zl=Zk."

I conclude: the output impedance of an anode in a cathodyne phase-splitter is high and remains high, but the feedforward from the cathode compensates for this and the potential increase in gain, resulting in a behaviour that imitates a low impedance, an *apparent* impedance equalling the cathode impedance if load conditions are identical. An informed appearance, not a blind truth.

I hope that my remarks will stimulate tube enthusiasts to a more cautious reading of the first part of Yaniger's article. Of course, all the above in no way changes one iota of the value of the second part of his article. I totally agree with him that adding an extra resistor in series with the cathode output is a mistake and deteriorates the cathodyne's performance instead of balancing it, as amply illustrated by Yaniger's measurements.

Peter van Willenswaard, Bergschenhoek, Netherlands

Stuart Yaniger replies:

I thank Peter for his interest and kind words. He brings up several points worth discussing.

Peter asks, "So how on earth does a triode 'know' that equal loads have been connected to anode and cathode, and then suddenly change its otherwise very different output impedances?" The answer is "feedback". Change anything in the cathode and this is reflected in what happens at the plate- and vice versa. The boundary condition that cathode and anode loads be identical is where the "magic" is.

On his second point, in the article I showed a Thevenin analysis of source impedances by calculating open circuit voltage divided by short circuit current with the very explicit boundary condition that the loads were equal and found source impedance at the two outputs to be equal and low. The calculation I used, Voc/Isc, is an accepted and standard definition of Thevenin source impedance.

Yet, if one considers Peter's suggestion of injecting a test current into one of the nodes (another common way of looking at source impedance), one sees a very different answer indeed! So how can we reconcile this seeming paradox?

We do so by noting that injection of a test current into only one of the outputs violates the explicit boundary condition ("equal loads"). To make this clear, let's consider a test current which is in phase with the signal from the plate output. If the test current is inserted into the plate output, the amount of current that the plate output sources to the load is reduced compared to the current delivered from the cathode output to the cathode load because of Kirchoff. Likewise, if the test current is injected into the cathode output (to which it is antiphase), the current drawn from the cathode side will now be higher than the no-test-current condition at the plate.

In order to honour the explicit boundary condition ("equal loads"), an equal and opposite test current should be injected into each of the outputs simultaneously. Under these conditions ("equal loads"), the source impedances at cathode and plate output are equal and low, and the results agree with the Thevenin analysis. This may be seen experimentally by considering the results I showed with capacitive loads on both plate and cathode outputs.