IMPEDANCE DISPUTE

Having read the exchange between Mr. Paul and Mr. Yaniger regarding the cathodyne/split-load phase inverter (April and June '09, Xpress Mail), I must support Mr. Yaniger before another audio myth is further perpetuated. It is a common misconception among audio amateurs that the output impedances of a cathodyne phase inverter are inherently unbalanced. This is *not* true, and this persistent falsity should be put to rest once and for all.

Perhaps this confusion arises when considering the output impedance from *one* output at a time, in which case the output impedances do indeed appear unequal. However, because a phase inverter which only uses one of its outputs is fairly pointless, this definition of output impedance is, too. As Mr. Paul correctly points out, provided the anode and cathode are at all times equally loaded, mutual feedback between each output and the grid causes the output impedances to become identical, and therefore so does the frequency/amplitude balance, at least over the normal audio range.

For some reason, Mr. Paul supports his argument by citing page 330 of the *Radio Designer's Handbook* (4th ed.), where it clearly states that "the equivalent source impedance [***for both outputs***]. . . is given by":

$$Ro = \frac{r_p R_L}{r_p + R_L(\mu + 2)}$$

where R_L = Rp = Rk

Perhaps Mr. Paul did not read all the way down page 330. In any case, this mathematical puzzle was also solved over half a century ago in:

Jones, G. E., (1951). Analysis of Split-Load Phase Inverter. *Audio Engineering*, **35** (12), pp 16+40-41.

And later by:

Priesman, A. (1960). Notes on the Cathodyne Phase Splitter. *Audio*, (April), pp 22-23.

I will not repeat the mathematical derivations here, as both seminal papers may be accessed on www.thermionic.info, and www.aikenamps.com/TI_Other.htm, respectively.

Mr. Paul also argues that "no justification is given for [the requirement for identical test loads] in any engineering textbook that I have ever seen." This is not surprising, because it is implied. If you test the circuit with only one output loaded, then you are not using the circuit as a phase inverter; if you do not apply all the necessary loads, then you are not testing the same circuit! No textbook would bother to make such an obvious statement.

As an academic curiosity, a similar process applies to an op amp arranged for balanced-to-single-ended operation, with equal value resistors used throughout. Mutual feedback to each input forces the input impedances to become equal despite their "apparent" inequality when considering only one input.

I can also supply an electronic copy if Mr. Paul wishes to read:

Peters, D. P. (1957). In Defense of the Split-Load Phase Inverter. Radio & TV News (November), pp 182+184.

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I read with interest the discussion between Mr. Yaniger and Mr. Paul about the output impedances of the phase splitter described in Mr. Yaniger's article. Mr. Yaniger states that the output impedance at the plate and cathode of the stage are equal as long as the load impedances are equal. Mr. Paul disputes that claim. At first blush it would seem that Mr. Paul's assertion must be correct, because it is well known and provable that a common plate stage (cathode follower) has a much lower output impedance than a common-cathode stage. However, the special case described by Mr. Yaniger—i.e., equal output impedances—is intriguing, so why argue about the point when some simple circuit analysis will provide a definitive answer?

For clarity, let me review what I mean by output impedance. A common way to model the output impedance of any voltage source is to consider such a source as consisting of a perfect voltage source—one with zero output impedance—in series with a resistor.

In **Fig. 1**, Rg represents the voltage source's output impedance, and R_L represents the load. For simplicity, I've made the assumption that the source's impedance is not frequency dependent. I think it will be clear to most readers that the value of Rg can be calculated by varying R_L and noting how Vout changes. If

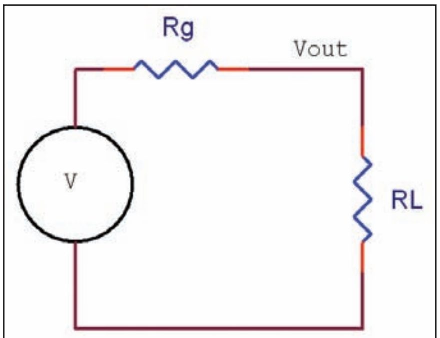

FIGURE 1: Impedance model.

you had two voltage sources and wanted to compare their output impedances, it would be sufficient to test them both with the same varying load resistances. If their outputs changed equivalently, then, by definition, their output impedances are equal.

Now on to the phase-splitter stage. Let's model the stage using a simplified hybrid-pi model (**Fig. 2**).

Vg represents the grid voltage. The current source represents the tube's transconductance, so the value of the current equals $g_m V_{gc}$. R_p is the plate resistor, R_c is the cathode resistor, and r_p represents the tube's internal plate resistance (the reciprocal of its output conductance). The principle simplification in this model is that none of the tube capacitances are shown. Strictly speaking, the model is therefore only accurate at DC. I am making the untested assumption that, within the bandwidth of interest, the capacitive reactances are so much larger than the plate and cathode resistors as to be of little import.

A quick look at the model shows that R_P and R_C are in series with each other, and in parallel with r_p. With that insight, the equations for the circuit can be easily derived. For better or worse, I have named voltages for the resistors they appear across. Also, I never design with tubes, so please excuse any labels that don't follow accepted convention.

Equation 1: $V_{r_p} = g_m V_{gc} \frac{r_p(R_p + R_c)}{r_p + R_p + R_c}$

Equation 2: $V_{R_C} = V_{r_p} \frac{R_c}{R_c + R_p}$

Equation 3: $V_{R_P} = V_{r_p} \frac{R_p}{R_c - R_p}$

Equation 4: $V_{gc} = V_g - V_{R_C}$

It's not necessary for the question at hand, but from these equations, you can derive the transfer function

$$\frac{V_{r_p}}{V_g} = \frac{g_m r_p (R_c + R_p)}{r_p + R_c + R_p + g_m R_c R_p}$$

Now, remember what I previously said, that if two voltage sources behave equally when tested with varying load resistors, those two load sources, by definition, have equal output impedances. Referring to equations two and three, you can see, in fact, that for any value of R_c and R_p, that V_{Rc} and V_{Rp} are equal to each other as long as R_c and R_c are equal to each other. Therefore, I have proven Mr. Yaniger's assumption that if the impedances at the plate and cathode are equal, then the stage does have equal output impedance at cathode and plate. Let me note for completeness that the equal impedances at both nodes would consist both of the discrete plate and cathode resistors as well as the input impedances of the following stage each node is connected to.

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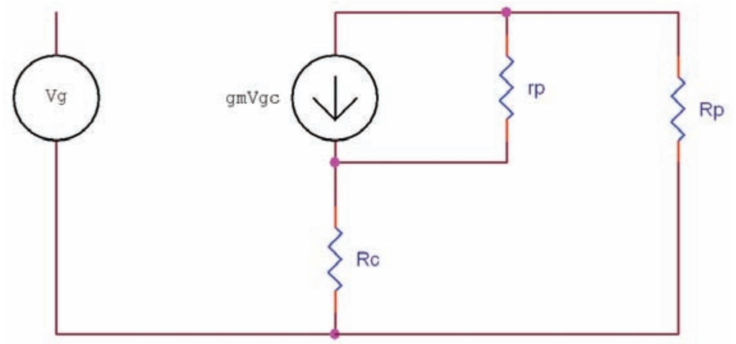

FIGURE 2: Example phase-splitter stage.

CONTRIBUTORS

Jan Didden ("paX, Part 1," p. 6) built his first OTL amp with 807 tubes 35 years ago. He has built speakers, preamps, and tape recorders, but is most interested in power amps, especially using error correction as discussed by Hawksford. Many of his projects have been published by *audioXpress*. Now retired from a career with the Netherlands Airforce and NATO, he tries to complete all those half-finished projects accumulated for lack of time. He now also has the time to travel to interesting audio events and interview audio luminaries. His projects are documented on his Linear Audio website.

Aren van Waarde ("Regulated Power Supply for Tube Projects," p. 16) is a biochemist working in the field of medical imaging (positron emission tomography.) He has worked as a Ph.D. student and a postdoc at several universities (including Leiden and Yale Universities) before accepting tenure at the University of Groningen. His passion for audio started on his ninth birthday when his parents gave him a Philips kit. Most of his current audio equipment (loudspeakers, radios, tuners, pre- and power amps, both tube and solid-state) is homemade.

Thomas Perazella ("Maintaining Your Balance, Part 2," p. 20) is a retired IT Director who has been actively involved in the audio hobby since building his first EICO FM tuner. He designs and builds custom speakers that minimize room effects and provide wide bandwidth, high dynamic range output. Protection of valuable components has also been a subject of interest and he has built devices to provide soft-start and voltage-monitoring functions for large groups of electronic devices as well as circuits to protect speakers against excess power and DC offsets. When not involved with audio, he enjoys cooking and precision pistol and rifle shooting.

James Frane (Review: THIEL SCS4 Loudspeakers, p. 30) has written for *The Audiophile Voice* from at least 2002 to present, as well as *The $ensible Sound*.

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David A. Rich (Review: Sony XDR-F1HD, p. 34) received his MSEE from Columbia University and his Ph.D. from Polytechnic University of NYU. He specializes in the design of analog and mixed-signal integrated circuits and has taught graduate and undergraduate courses in integrated electronics and electroacoustics. Student work under his guidance, including a novel high-efficiency mixed-signal integrated power amplifier, has won numerous awards. His industrial positions include Technical Manager at Bell Laboratories. His portfolio has spanned the design of audio ICs for Air Force One to RF ICs for wireless cell phones, and his innovations have earned 14 patents. He is a Senior Member of the IEEE and has frequently served as chairperson for technical and panel sessions at IEEE conferences. He has been a member of the AES signal processing technical committee and has been Technical Editor for *Audio Critic* and *Sensible Sound*. He is the head of the music committee of the Bethlehem Chamber Music Society.

Gary Galo (Review: PS Audio Digital Link III, p. 36) is Audio Engineer at The Crane School of Music, SUNY Potsdam, where he also teaches courses in music literature. A contributor to AAC since 1982, he has authored over 230 articles and reviews on audio technology, music, and recordings. He has been the Sound Recording Reviews Editor of the *ARSC Journal* (Association for Recorded Sound Collections) since 1995, was co-chair of the ARSC Technical Committee from 1996 to 2004, and has given numerous presentations at ARSC conferences (www.arsc-audio.org). Mr. Galo is also a frequent book reviewer for *Notes: Quarterly Journal of the Music Library Association*, has written for the *Newsletter of the Wilhelm Furtwängler Society of America*, and is the author of the "Loudspeaker" entry in *The Encyclopedia of Recorded Sound in the United States*, 1st edition.

Chuck Hansen (PS Audio DLIII DAC Measurements, p. 40) is an electrical engineer and holds five patents in his field of engineering. He began building vacuum-tube audio equipment in college. He plays jazz guitar and enjoys modifying guitar amplifiers and effects to reduce noise and distortion, as well as building and restoring audio test equipment. He enjoys sailing and has over 150 magazine articles to his credit.