Measurement of Amplifier Internal Impedance

W. H. ANDERSON*

An analysis of the possible errors which may be encountered with various methods of measuring output impedance, and a suggested method which minimizes the errors.

NINETEEN FIFTY-FIVE will probably go down in automotive history as "Wraparound Windshield Year." For similar reasons it will likely be called "Controlled Damping Year" in audio circles. While not wishing to get involved in the controversy as to how much damping is optimum, it is surely safe to point out that the source impedance the speaker sees is important for two reasons:

1. It determines the terminal voltage behavior in the face of inevitable speaker impedance change accompanying frequency change.
2. It is the load when the speaker acts as a generator and releases stored energy.

The determination, on paper, of such source impedances generally presents no particular problem. When no feedback is present, the speaker looks back into the secondary ohmic resistance plus the resistance transformed down from the primary. This primary resistance includes the primary ohmic resistance plus the a.c. plate resistance of the tubes. For instance, *Fig.* 1 shows two 6V6 triodes (plate resistance about 2000 ohms each) feeding a 13-ohm load.

The source resistance seen by the load would be $1.0 + (2 \times 2000 + 1000)(13/13{,}000) = 6.0$ *ohms*. If negative voltage feedback alone is present from secondary back to the amplifier, this 6 ohms will drop by the same factor as the gain is reduced by the application of the feedback. For instance, if the input required when feedback is applied (for a constant output) is 5.5 times the input required when feedback is absent, the source impedance will drop to $6/5.5 = 1.1$ ohms.

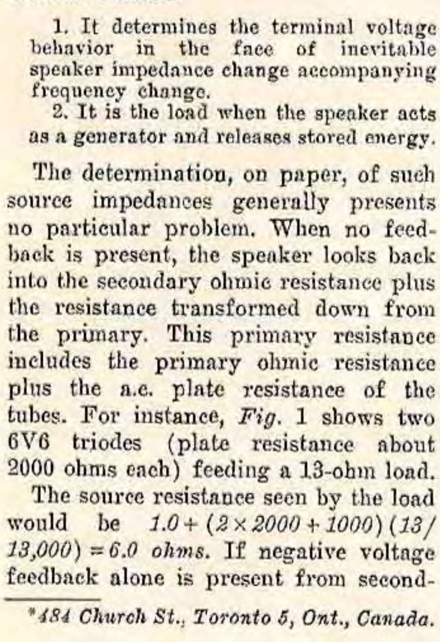

Fig. 1. Experimental amplifier output circuit.

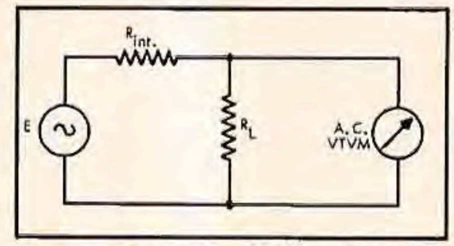

Fig. 2. Constant voltage equivalent circuit.

If negative current feedback only were applied, the impedance would rise but not necessarily by any simple factor related to gain drop. The catch is that many feedback circuits are hard to exactly classify as voltage or current, negative or positive, and in such cases calculation is indeed difficult.

Taking a cue from Lord Kelvin, the obvious next step is to attempt a measurement. There seems to be no widely accepted standard and only two suggested methods could be discovered in the literature.

The first approach[1] is, briefly, to view the output circuit (*Fig.* 2) as a constant-voltage source which can be measured with the load terminals open circuited—that is, with $R_L = \infty$. Then if R_L is dropped in value until the output voltage drops to one half the open circuit value, R_L must equal R_{int}.

There seem to be two more or less related objections to this approach:

(1A) Since the load seen by the tubes may vary from a pure inductance to a very low resistance, the assumption of constant voltage, let alone constant waveform, is difficult to justify.

(2A) An amplifier with low source resistance has a very stable output voltage and it may be almost impossible to reduce the terminal voltage to one-half without encountering error related to resistance of the leads connecting the amplifier to its load.

"Backward Driving" Method

The second method,[2] *Fig.* 3, is to drive a known current through the output terminals of the amplifier and ascertain the voltage drop it produces. There are two possible objections to this technique:

(1B) If feedback is being taken from the output terminals in some manner, care must be taken that the equipment involved in measurement does not disturb the feedback arrangements.

(2B) If the amplifier is being operated beyond straight class A, the plate resistances rise as the tubes become cut off for part of each cycle, (theoretically up to 2.0 times the class A value when operating Class B),[3] consequently the source impedances rise when going from class A to AB to B. This method would not reveal this change since there is no signal coming through the amplifier in the usual way.

It might be possible to run enough secondary current so that the primary voltage swing will exceed E_{bb} of the stage and in this way simulate normal operation. This would, however, require an external source of known internal resistance whose power rating would be at least the damping factor squared times normal power output of amplifier under test. In this instance,

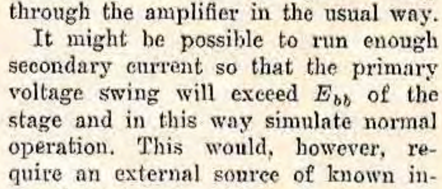

Fig. 3. "Backward driving" method of determining internal impedance.

---

*484 Church St., Toronto 5, Ont., Canada.

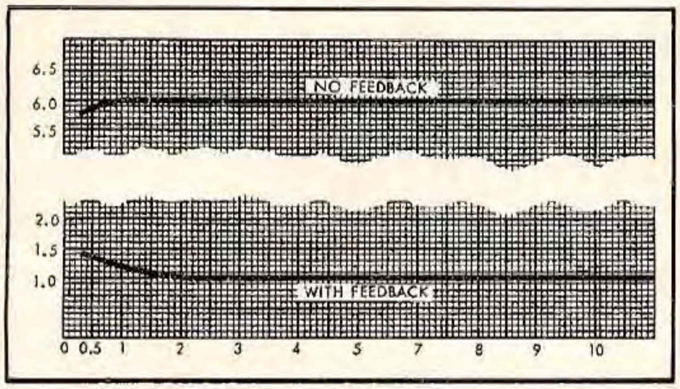

Fig. 4. Calculated internal impedance for various values of "R".

this would amount to $(6/1.1)^2 \times 4 = 119$ watts. Here again the lower the internal resistance, the greater the problem in measuring it.

Examples

A small push-pull triode 6V6GT amplifier of conventional class AB design was used for a number of tests described. About 15 db voltage feedback from the output transformer secondary was available but could be readily removed for comparison. The calculated source impedances were as outlined above—6 ohms without feedback and about 1 ohm with feedback. With the rated load of 13 ohms, about 4 watts power output could be obtained with tolerably small distortion throughout the range from 40 to 15,000 cps. Naturally, the power-frequency response was smoother when feedback was used.

The open circuit/half voltage method was tried first. It gave answers that were almost dead on the calculated values *provided* the level of measurement was kept quite low (a quarter of a watt or so) otherwise severe squaring was encountered as the load resistance was dropped. See (1A), preceding. If this distortion was disregarded, nearly any answer one wanted could be produced because the voltmeter reads the square root of the sum of the squares of the various frequency components and the reading is a function of the degree of distortion as well as the magnitude of the fundamental.

Figure 4 is an illustration of the point raised in (1B) regarding the *Fig.* 3 layout. Since the impedance of the step-down transformer secondary was negligible, the current metering resistor *R* becomes the amplifier load. The magnitude of this resistance is of substantial importance when feedback is used since the signal that goes back up the feedback path and is amplified sees the resistor as the load.

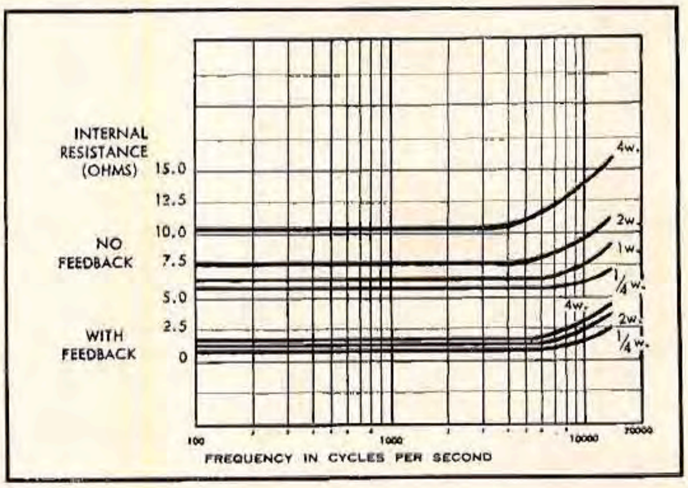

Fig. 6. Internal impedance vs. power level.

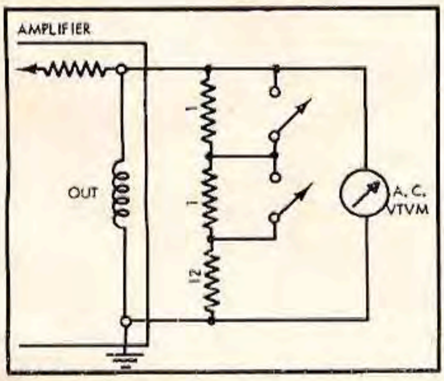

Fig. 5. "Small increment" method of measuring internal impedance.

To get around objection (1A) if one makes only a *small* change in the load resistance, the internal voltage of the amplifier should only be slightly affected. If it then were possible to measure the *small* change in output voltage and divide it by the *small* change in current through the load, the quotient would be the internal impedance (see Appendix). Accordingly, the load was changed from 13 to 14 ohms, then from 13 down to 12 ohms (see Fig. 5), the internal impedance computed and the values averaged. Incidentally, the two values in each pair were always within ten per cent and usually much closer. This was done for several power levels, both with and without feedback and the results are shown in *Fig.* 6. Note that at low power levels the internal impedance drops down to the computed level, which after all did not take into account class AB operation.

The difficulty with this method (particularly when feedback was on) was that one was required to read extremely small voltage variations across the full load and then divide by the known resistance in both cases in order to find the current change and, subsequently, the source resistance. Some streamlining of the procedure may be effected by using the layout of *Fig.* 7. By the use of the voltmeter across the 1-ohm resistor alone, we have the current without further computation, only now it is necessary to multiply this voltage by the number of ohms total load in order to find the amplifier terminal voltage in each case. The simple advantage of this layout lies in the fact that with very low source impedances the output current rises sharply with a drop in load resistance and since the meter is essentially a current-measuring device, greater accuracy can be obtained than if we were trying to observe a total voltage change. The values obtained

(*Continued on page 48*)

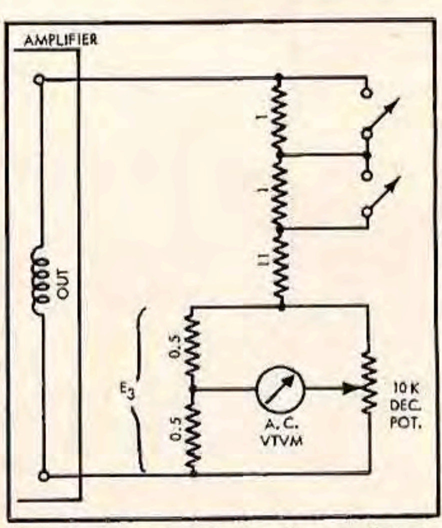

Fig. 7. Current metering for small-increment method.

AMPLIFIER

(from page 23)

from this technique were as close to those displayed in *Fig.* 6 as resistor accuracy and meter reading ability would permit, in other words within about 5 per cent.

The "Unbalanced Bridge" Method

In an attempt to refine this method still further and measure the voltage change more accurately, an unbalanced bridge arrangement was used (see *Fig.* 8). The philosophy here is that the voltmeter reads $E_3[0.5 - R_2/(R_1 + R_2)]$. Furthermore, if the two half-ohm resistors are not exactly equal, their relative value may be established by initially balancing the bridge and noting the reading on the decade potentiometer. This reading is then used in place of 0.5 in the foregoing formula. One-ohm increments of the total load are taken as above and each time the bridge is unbalanced enough to produce, say, .01 volt. E_3 is then computed and handled in the same manner as the voltmeter reading in the preceding method. This setup is perhaps the most accurate but requires more elaborate equipment.

INTEGRITY IN MUSIC

THE NEW STROMBERG-CARLSON COMPONENTS

Integrity in Music, as applied to high fidelity components, means reproduction which adds nothing to, or takes nothing from, the original performance.

Stromberg-Carlson's choice of this slogan is no accident. Just as your purchase of a component system is not a casual investment, our attitude toward the manufacture of components is very serious indeed. Each piece of gear must reflect the highest possible achievement of engineering, production, and musical skill. The guiding minds, hands and ears of the Stromberg-Carlson component group are those of professional electronic and acoustic engineers with extensive musical training.

The musical sound of our new components was the final critical test before they were made available to you.

We proudly submit our specifications to your critical judgment. These specifications are accurate and conservative. We have declared ourselves out of the "battle of exaggerated specifications." Please study our specifications to see how the phrase "Integrity in Music" takes on true life and meaning.

Selected For Display At The Vienna International Fall Fair.

ASR-433 STEREO AMPLIFIER

The most important aspect of stereo is *stage effect*. The instruments of the orchestra should come back to you from their exact positions on the stage. How?

The answer is *balance*. The ASR-433 is the stereo amplifier with "*Tone-signal Balance*," the surest method of achieving this realistic *stage effect*.

The ASR-433 is a superb monaural amplifier as well, giving you a full 24-watt output. The electronic crossover at 3,000 cycles provides output for 12 watts low and 12 watts high frequency operation. Every function has its own control for each channel and a master volume control is provided.

SPECIFICATIONS:

POWER OUTPUT: 24 watts (2-12 watt channels). FREQUENCY RESPONSE: 20-20,000 cycles ± 1 db. HARMONIC DISTORTION: Less than 1%. NOISE LEVEL: 63 db down. INPUTS: Magnetic Phono, Ceramic Phono, Tape Head, Tuner and Aux. Tape. OUTPUTS. 4, 8, 16 ohms and dual Tape Out. LOUDNESS CONTROL: In-out, continuously variable. TONE CONTROLS: Bass 15 db droop, 15 db boost; Treble 14 db droop, 12 db boost. EQUALIZATION: RIAA Mag. Phono. NARTB Tape Head. TUBES: 2-12AX7/7025, 2-6AV6, 2-6U8, 4-EL84. CHANNEL SELECTOR: Channel "A," Channel "B," Stereo, Monaural, Crossover (at 3000 cycles). DIMENSIONS: 13½" W, 13⅜" D, 4⅝" H. PRICE: $129.95* (Audiophile Net).

**All prices are Zone I.*

See your dealer or write to us for full data on our complete new line of amplifiers, speakers, speaker systems, enclosures and program sources.

"There is nothing finer than a Stromberg-Carlson"

STROMBERG-CARLSON

A DIVISION OF GENERAL DYNAMICS CORPORATION

1418C N. Goodman Street • Rochester 3, N. Y.

Electronic and communication products for home, industry and defense; including High Fidelity Consoles; School, Sound, Intercom and Public Address Systems.

S-C GD

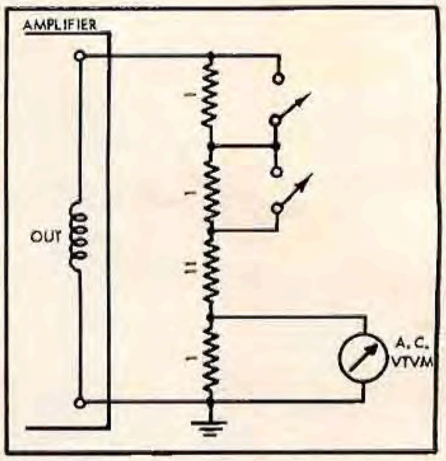

Fig. 8. Bridge method for accurately measuring small voltages.

No significant differences from previous results were recorded here.

Seeking a somewhat more direct technique and noting that internal resistance determines the *power* change when the load is changed, an accurately calibrated power output meter of the General Radio 583A or 783A and Daven OP961 types were utilized. Two output powers were recorded with two different loads—in this case, 12.5 and 15 ohms were the closest to the rated load. If we assume that load R_{L1} gives greater power output that R_{L2} (and thus $F_R > 1$) we can write:

$$\frac{\left(\frac{E}{R_{int}+R_1}\right)^2 R_1}{\left(\frac{E}{R_{int}+R_2}\right)^2 R_2} = \frac{\textit{Power output with load } R_{L1}}{\textit{Power output with load } R_{L2}} = P_R$$

Performing the necessary algebra

$$R_{int} = \frac{R_1R_2(P_R-1) \pm \sqrt{P_RR_1R_2}\ (R_1-R_2)}{R_1-P_RR_2}$$

Use the negative sign in the numerator when the denominator comes out negative—positive when the denominator is positive. The only difficulty with this system (other than the thorny formula above) is that the power meter indications tend to become unreliable at the higher frequencies, but below 10,000 cps results tallied with *Fig.* 6.

As a final check, it was decided to use two frequency components—one coming through the amplifier and one being run through the output circuits—and measure them separately by means of a wave analyzer (see *Fig.* 3). Make $R = 13$ ohms and substitute a low-output-impedance signal generator for the Variac. Note that the amplifier is correctly terminated as the impedance of the step-down transformer secondary is extremely small. This now corresponds to a stored-energy transient situation as encountered in audio amplifiers. The impedance seen by the signal being fed back into the amplifier may be determined by simple voltage-division principles since we know the magnitude of the voltage supply and the drop across a known resistance. As long as we keep within reasonable frequency bounds, there will be no appreciable phase shift. Suffice to say that the impedance seen by this "backward" component is almost entirely a function of the magnitude and frequency of the signal coming through the amplifier in the normal way. "Almost entirely" because it is possible to create transformer saturation with this driven current, but this is scarcely likely to happen under normal amplifier usage. This, too, produces a set of values within normal measurement error of those displayed in *Fig.* 6.

Since many of these calculations involve small differences between relatively large quantities, it is mandatory that the resistors, voltmeters and other paraphernalia be accurate to one-half of one per cent or better. Æ

REFERENCES

[1] Richter, "Measuring amplifier internal resistance. AUDIO ENGINEERING, October, 1948.

[2] Mitchell, "Audio amplifier damping." *Electronics*, September, 1951.

[3] W. L. Everitt, *Communications Engineering* (second Ed.). McGraw Hill, p. 568.

APPENDIX

(Refer to Fig. 2)

$$I_1 = \frac{E}{R_{int} + R_{L_1}}; \qquad I_2 = \frac{E}{R_{int} + R_{L_2}}$$

$$E_{out_1} = I_1 R_{L_1}; \qquad E_{out_2} = I_2 R_{L_2}$$

$$E = I_1 R_{int} + I_1 R_{L_1} = I_2 R_{int} + I_2 R_{L_2}$$

$$I_1 R_{int} + E_{out_1} = I_2 R_{int} + E_{out_2}$$

$$R_{int}(I_1 - I_2) = E_{out_2} - E_{out_1}$$

$$R_{int} = \frac{E_{out_2} - E_{out_1}}{I_1 - I_2}$$

FEEDBACK

(from page 32)

nominal value, the damping factor of the amplifier is 4, a value which provides good operation with most speakers. However, other damping factors can be used, and while absolute isolation between load and feedback is not obtained, a sufficient degree is realized to be of positive benefit. For example, a capacitive load will not display ringing at any setting of the control. Moreover, the system has the beauty of supplying variable damping with insignificant increase in distortion, and maintains a constant amount of feedback so that output level is independent of the setting of the damping control. The complete schematic of the amplifier is shown in *Fig.* 2. Æ