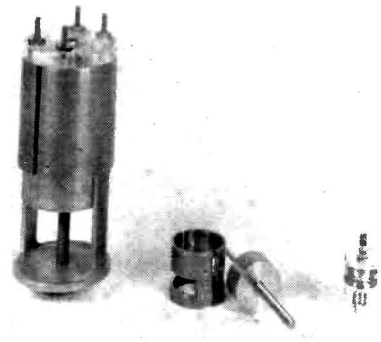


FIG. 2—Photograph of three experimental wide-range resonators that may be applicable to uhf and vhf television

in Fig. 1A. With the same 6K4 tube, the oscillation range is 220 to 520 mc. The small resonator at the right is the same type. With no external connections, the tuning range is 440 to 1,900 mc; with the 6K4 tube, the oscillation range is 340 to 550 mc.

As oscillators, the maximum frequencies of all three resonators appear to be limited by tube capacitances and lead inductances. For applications where there is no appreciable external loading of the resonator, such as an absorption wavemeter, the frequency range is limited by the smallest radial clearance that can be obtained between the tuning slug and the resonator's inner surface.

REFERENCES

(1) Vernon H. Aske, Front End Design for a 400-Mc Receiver, *Tele-Tech* 9, p 46, Sept. 1950.
(2) Eduard Karplus, Wide-Range Tuned Circuits and Oscillators for High Frequencies, *Proc. IRE* 33, p 426, July 1945.

Boucherot Compensation

BY HANS E. HOLLMANN
Oxnard, California

THE ELECTRONICS QUIZ in the December 1950 and January 1951 issues of ELECTRONICS deserves more attention for it reveals the phenomenon of aperiodically compensating any impedance by a conjugate impedance. This compensation, based on a theorem of complex algebra, has important application in the Boucherot circuit named after the French inventor.

We are dealing with the theorem that any complex number $Z' = a + jb$, where j can be made real

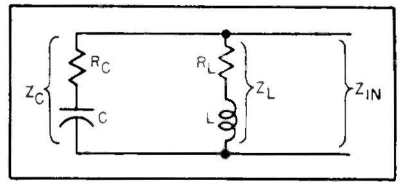


FIG. 1—Basic circuit shown in Electronics Quiz problem

with the aid of another complex number $Z'' = c - jd$. A simple addition yields: $Z_{IN} = Z' + Z'' = a + c + j(b - d)$ which becomes real for $d = b$. Another combination is the reciprocal sum of the reciprocals

$$Z_{IN} = \frac{1}{\frac{1}{Z'} + \frac{1}{Z''}} = \frac{Z'Z''}{Z' + Z''}$$

$$= \frac{ac + bd + j(bc - ad)}{a + c + j(b - d)}$$

Now, there exist two conditions for making the expression real. The first is $c = a$ and $d = b$ because the imaginary terms disappear separately in numerator and denominator so that $Z_{IN}' = (a^2 + b^2)/2a$. The second condition is $c = a = \sqrt{bd}$, and yields

$$Z_{IN}'' = \frac{2a^2 + ja(b - a^2/b)}{2a + j(b - a^2/b)} = a$$

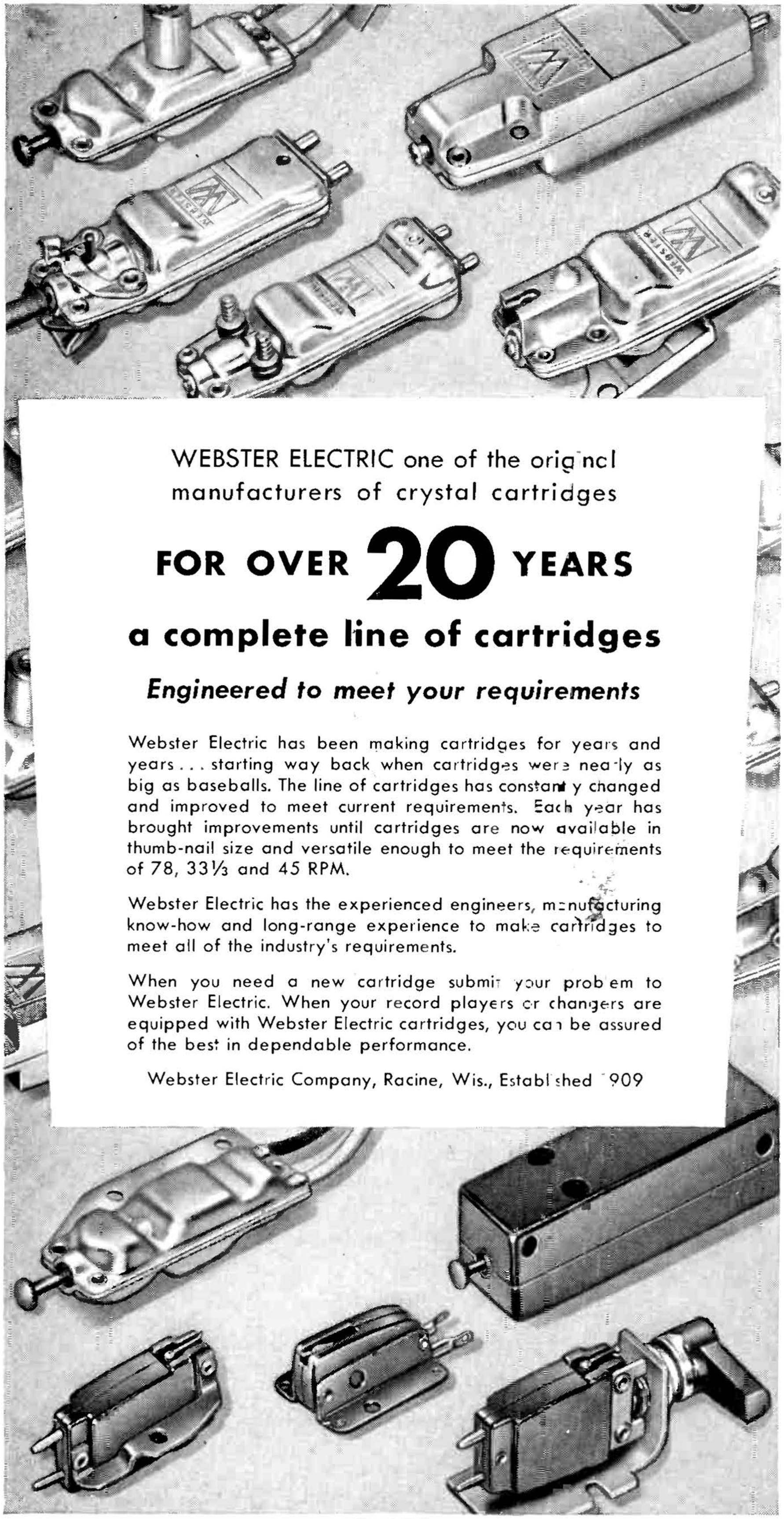
According to Fig. 1 let us examine the impedance $Z_c = R_c + 1/j\omega C$ of the capacitive branch shunted by the inductive branch having the impedance $Z_L = R_L + j\omega L$. If we assume $R_C = R_L = R$, the impedance of the network becomes:

$$_{IN} = \frac{Z_L Z_C}{Z_L + Z_C} = \frac{(R + j\omega L)(R - j/\omega C)}{R + R + j(\omega L - 1/\omega C)}$$

$$= R\,\frac{L/RC + R + j(\omega L - 1/\omega C)}{R + R + j(\omega L - 1/\omega C)}$$

Following the outline, Z_{IN} becomes real if both imaginary terms disappear. That is the condition $L = C$ of parallel resonance with $Z_{IN}' = (1 + R^2)/2R \rightarrow R/2$. On the other hand, numerator and denominator differ only by their first terms. Hence, setting $L/RC = R$ or (in accordance with $a = \sqrt{bd}$) $R = \sqrt{L/C}$ yields $Z_{IN}'' = R$, the aperiodic or antiresonance case of the quiz problem.

The conversion of an originally complex network into a real one, that is, into a resistance, by supplementing a complex conjugate impedance, either in series or in paral-



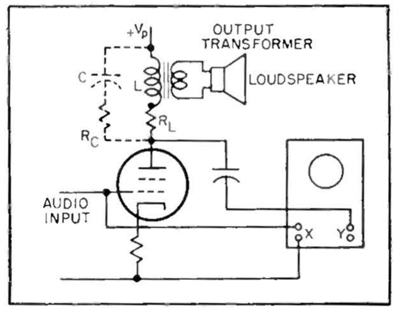


FIG. 2—Loudspeaker analogy studied after Boucherot

lel, is of great importance for many practical purposes. A typical example is the Boucherot compensation in the end stage of an audio amplifier, a triode, pentode, or beam tetrode loaded with a matching transformer as shown in Fig. 2. As is well known, the equivalent network of the transformer seen from the plate, in fairly good approximation, is an inductance L in series with a resistor R_L. The reactive component brings the tube out-of-phase so that harmonic as well as intermodulation distortions occur. These distortions limit the value of a multigrid tube as compared to a simple triode and counterbalance the inherent advantage of the higher gain. Today there are two conflicting opinions in rating an end triode exhibiting a lower plate resistance and useful efficiency under low distortions as compared to multigrid tubes requiring less driving power at the expense of distortions even at moderately high frequencies.

In order to shift the balance in favor of multigrid tubes, the Boucherot compensation is of significant importance because it makes the multigrid tubes operate purely in-phase and improves the power output versus distortion figure. The suggestion: "go ahead by going back—back to triodes"[1] seems to be premature as long as the Boucherot compensation is not taken into consideration.

The improvement which is achieved by the Boucherot network is clearly demonstrated by means of the dynamic transfer characteristic. According to Fig. 2, the end stage is driven by an a-f voltage which also controls the X-input of the oscilloscope, the Y-deflection of which is produced by the plate voltage. If the test device is driven

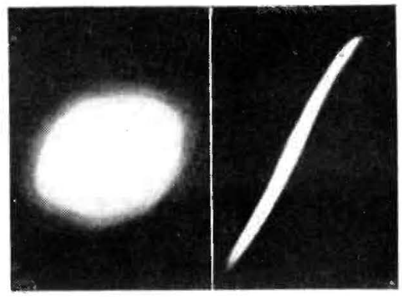


FIG. 3—Oscilloscope figures show improvement in performance

with various frequencies, as delivered by a radio or phonograph pickup in the form of music or speech, the resulting Lissajous figure on the oscilloscope screen fluctuates according to the momentary frequencies and amplitudes. The result, taken during sufficiently long exposure time, is the blurred figure shown at the left in Fig. 3, disclosing innumerable Lissajous ellipses of various forms and sizes superimposed upon each other during exposure.

As soon as the output transformer is compensated by the dotted Boucherot network, the end stage operates in-phase and the Lissajous ellipses contract to the pure-in-phase characteristic shown at the right in Fig. 3. Needless to say, the harmonic and intermodulation distortions diminish to a considerable extent bringing to the listener a faithful reproduction of the original speech or music.

The oscillogram reveals the effect of the Boucherot compensation only in a qualitative manner. A better insight is obtained by measuring the harmonic or the intermodulation distortions with and without Boucherot compensation. Figure 4 illustrates such an experiment[2], namely the intermodulation factor of an end tetrode in relation to the measuring frequency when the tube is driven by a constant input voltage. While the output phase condition produces increasing modulation, the distortions decrease slightly as soon as the Boucherot compensation is applied.

Certainly the Boucherot circuit is not perfect and cannot produce an ideal condition of operation. In comparison to the evident advantages, however, the following disadvantages must be mentioned. First, the equivalent network of the transformer and its loudspeaker

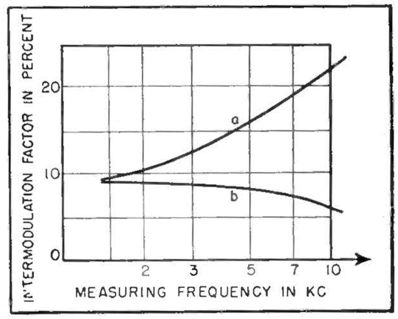


FIG. 4—Curves show actual measurements on equipment using Boucherot compensation

load holds only within certain limitations. Second, there is a power loss in the compensating branch which increases toward higher frequencies thus making the frequency response poorer. This can be compensated for by other means, for example, by filter circuits in the driver stage or in the feedback loop.

After all, the disadvantages do not count too seriously when compared with the pure-in-phase condition and the associated reduction of distortions in the most important output stage.

REFERENCES

(1) W. Bowen, Triode versus Pentode, ELECTRONICS, p 268, Nov. 1947.

(2) A. V. Lüpke, Verbesserung der Wiedergabe mit Lautsprechern hinter Mehrgitterröhren durch Verwendung der Boucherot-Schaltung (Improvement of loudspeaker quality when driven by multigrid tubes with the aid of the Boucherot circuit), *Zeits. für Tech. Physik*, Vol. 23, p 119, 1942.

Noise Figure Standards

THE NOISE FIGURE, a fundamental measure of the quality of linear electrical networks, is of basic importance in radar, telemetering, and all communications. In these systems some of the limitations on reliability, sensitivity, and distance are set by the type and magnitude of noise in the device as well as by the noise produced ahead of the network input terminals. In order to assist laboratories and industry in the evaluation of this important factor, the National Bureau of Standards is offering a calibration service for the noise figure in the frequency range of 500 kc to 30 mc.

The noise figure of a linear network is the ratio of the available noise power at the output (the to-