Proceedings of
The Radio Club of America, Inc.

Founded 1909

Volume 29, No. 4

1952

PRACTICAL ASPECTS OF THE R-J SPEAKER ENCLOSURE

by

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THE RADIO CLUB OF AMERICA
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PROCEEDINGS
OF THE
RADIO CLUB OF AMERICA

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PRACTICAL ASPECTS OF THE R-J SPEAKER ENCLOSURE

by
WILLIAM JOSEPH*
F. ROBBINS**

Presented before the Radio Club on October 9, 1952

Commercial high-fidelity reproducing equipment has for some time been available at prices low enough to permit widespread use in home installations. Tuners, amplifiers, cartridges and speakers which can handle the range from 50 - 10,000 cycles per second are today quite reasonably priced and equipment handling 30 - 15,000 cps is available in the higher price ranges. Speaker development has reached the stage where the former range can now be handled by single-cone speakers and the latter range by duplex or multi-way speaker systems. Most of the progress taking place in speaker development over the last decade has been mainly in extension of treble range, low bass reproduction in speaker techniques having preceded treble development.

Reproduction of the low bass end, however, is a function not only of speaker but of speaker enclosure as well. As almost all 12" and 15" speakers designed for the hi-fidelity market are capable of reproducing down to 50 cps and below, the responsibility for low bass reproduction today rests almost entirely on the speaker enclosure. Unfortunately, space limitations in the modern home mitigate against the use of large enclosures and in most home systems the octave below 100 cps is generally missing or is strongly curtailed. While such systems would sound balanced and pleasing before the full treble range became available and do indeed sound better if the amplifier treble control is cut back, it is generally found today that home systems are operated with the treble control flat and with bass control considerably boosted in an attempt to improve balance. While this boost in the 100-200 cps range may help matters somewhat there is actually no true bass "feeling" to such reproduction. It was considered worthwhile, therefore, to develop a small enclosure which would extend the bass range to at least 50 cps, and if possible to attempt to attain this result without resonant peaks, but retain good damping and transient response. Resonant peaks in the bass range produce "boom" and barrelly" speech reproduction, while poor transient response "muddies up" the bass.

A brief consideration of existing systems capable of 50 cps response will be pertinent in tracing the development of the R-J system, and the following systems will be briefly considered.

1. Flat baffle
2. Open Back box
3. Closed box
4. Horns
5. Bass Reflex
6. R-J.

1. <u>A flat baffle</u> will have to be 11 feet square. If the speaker itself resonates at 50 cps, there will be a bump in the pressure-response curve at this frequency and the response will fall off below at 18 db per octave.

2. <u>Open back boxes</u> are not suitable. A 7 cubic foot open back box 4" from the wall produces a walloping "boom" at 100 cps[1] and response drops off below at 18 db per octave. Below 100 cps frequency doubling and tripling distortion is very great.

3. <u>Closed boxes</u> need to be very large. A 15" speaker will require 12 to 18 cubic feet of air depending on the speaker compliance.

4. <u>Horns</u> provide high efficiency and good transient response. For 50 cps, the horn works out to a mouth diameter of 6'-8" or its area equivalent, and a length of about 8 ft. This is a little

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[1] "Loud Speaker Enclosures", Plach & Williams Audio Engineering, July 1951.

bulky for home use, however, Mr. Klipsch[2] has been able to ingeniously fold the horn so as to require only 13 cu. ft. of space.

5. Bass-Reflex. In pursuing small enclosure design, it was felt that the most fruitful field for investigation lay in the direction of resonating systems. A resonating column or chamber will produce sound with very little energy to activate it. Consequently, proper design may achieve useful sound output at some point in the register where system response would otherwise fall off.[3] The bass-reflex enclosure is an example of this kind of a system which, until recently, offered the closest approach to meeting the space problem.[4]

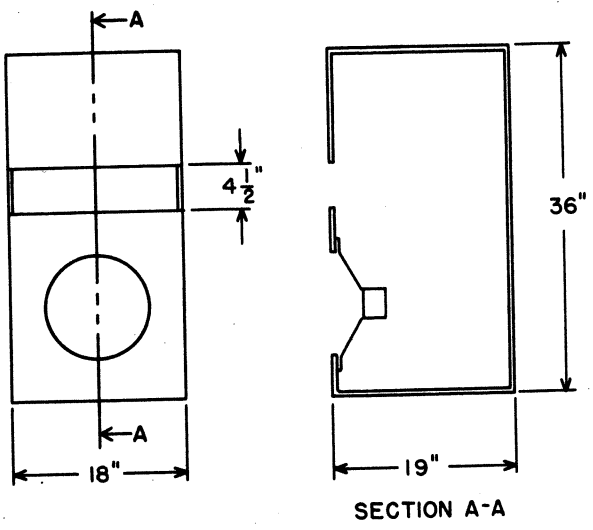


Figure 1

The demonstration bass-reflex as shown in Figure 1 consists of an enclosure with a speaker mounted in it and a port hole in the enclosure near the speaker. The first step in the design of the enclosure requires that the air resonance of the enclosure occur at the free-air cone resonance of the speaker.

The air resonance of the bass reflex enclosure can be closely determined by

$$f = \frac{c\ (A)^{\frac{1}{4}}}{2\pi\ (V)^{\frac{1}{2}}}$$

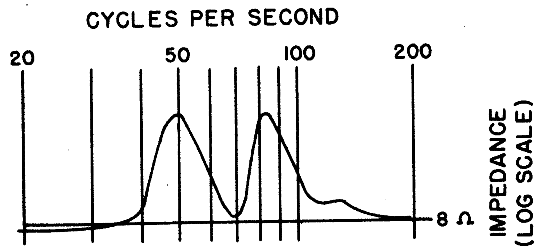
where: A is the area of the port
V is the volume of the enclosure
C is the velocity of sound in air.

The bass reflex used in the demonstration employs a 12" speaker with a free air cone resonance of 63 cps. To determine the volume V required

$$V = \left[\frac{2070\ (A)^{\frac{1}{4}}}{f}\right]^2$$

where: A is in sq. in.
f is in cycles per second.

Using A of 75 sq. in. and f of 63 cps, V comes out 9400 cu. in. Adding another 400 cu. in. for the speaker is 9800 cu. in. or 5.7 cu. ft.



IMPEDANCE CURVE
8 OHM 12" SPEAKER
63 CPS FREE AIR CONE RESONANCE
IN 5.7 CU. FT. BASS
REFLEX ENCLOSURE

Figure 2

Bass reflex enclosures must be carefully tuned after mounting the speaker to produce optimum results. Since the enclosure is generally purchased separately, and the speaker mounted within it without further adjustments, it is seldom that proper results are obtained. This is one of the major drawbacks of the bass reflex. When properly tuned, a bass reflex will exhibit two impedance peaks of equal amplitude, equally spaced in frequency above and below the speaker free air cone resonance. The impedance curve of the system with an 8 ohm 12" speaker is shown in Figure 2.

Exploring the possibilities for appreciable reduction in size of the bass-reflex enclosure, it becomes evident from inspection of the above equations that this may only be accomplished by reduction of port areas. Basically, the enclosure air resonance must occur at the free air cone resonance of the speaker where the speaker would otherwise oscillate with very little damping. The enclosure air resonance, being out of phase with the speaker restricts the tendency for large movements of the speaker cone while at the same time sound radiation from the port area takes over and helps to provide acoustic output at this frequency.

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[2] "Design of Compact Two Horn Loudspeaker", Paul W. Klipsch Electronics, Feb., 1946.

[3] "Acoustical Labyrinth", B.J. Olney, Electronics, April, 1937.

[4] "Sound Translating Device," A.L. Thuras, U.S. Patent #1,869,178 - July, 1932.

If the port area is reduced, acoustic radiation; which is proportional to the port area, drops off correspondingly and the desired sound output is not obtained. In addition, if the port area becomes too small the enclosure begins to approach closed box performance. There is therefore, a law of diminishing returns in operation and as a result, ports are generally compromised to about 75% of the speaker area. Sometimes the further addition of a duct added to the port is employed. By this means a further small reduction in volume can be obtained.

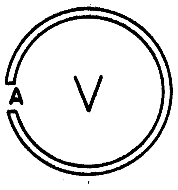


Figure 3

7. R-J. In pursuing the design of a small enclosure various types of resonant principles were explored and an adaptation of the Helmholtz resonator was finally adopted. In this type of resonator, (Fig. 3) the mass of air in the opening A swings back and forth at resonance and the air in the cavity V acts as a resisting spring against the movement of the air in the opening. The combination sets up a system analagous to a weight on a spring and has a resonant frequency determined by the mass and the compliance of the arrangement. The equation for the resonant frequency of the resonator is, as above,

$$f = \frac{c \ (A)^{\frac{1}{4}}}{2\pi \ (V)^{\frac{1}{2}}}$$

Helmholtz resonators are characterized by extremely high Q, and if a speaker is placed within a resonator, the response curve will exhibit a very high peak at resonance. If, however, some means to control the Q can be incorporated into the system, a small enclosure could conceivably be designed which would permit flattening the peak. A practical form of enclosure which attains this end takes the form shown in Figure 4.

The system still acts as a Helmholtz resonator with the further modication imposed by the creation of a duct system, indicated by arrows on Figure 4, between the back cavity and the frontal opening. The resonant frequency of an enclosure with a volume of 4800 cu. in. and an area of 64 sq. in. calculates out as follows:

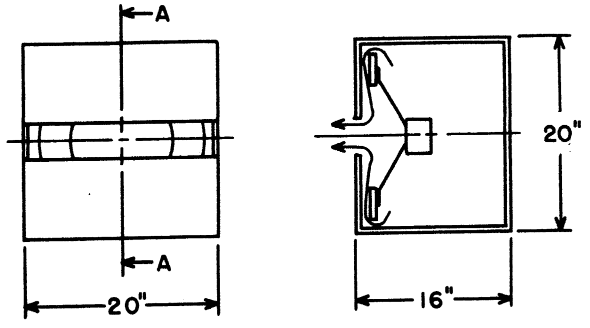


Figure 4

$$f = \frac{(1080) \ x \ (12) \ x \ (64)^{\frac{1}{4}}}{2\pi \qquad (4800)^{\frac{1}{2}}} = 84 \text{ cps.}$$

Actually close calculations require several refinements to take into account the effect of duct length and the end corrections.

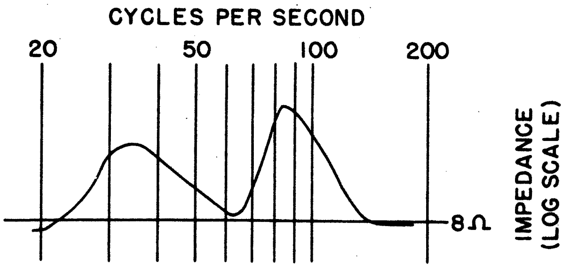
Control of the circuit Q is obtained by varying the spacing of the duct produced between the frontal board and the speaker board. By decreasing this spacing it is possible to introduce acoustic resistance to lower the Q and increase damping. The acoustical resistance of a slot is expressed by

$$Ra = \frac{k\ell}{t^3 w}$$

where: K is a constant
is the length of the duct passage
w is the width of the duct passage
t is the thickness of the duct passage (the spacing between the frontal board and the speaker board)

The acoustical resistance is a function of the third power of the spacing and becomes quite critical as t becomes small. Halving the spacing increases the acoustic resistance 8 times. By experimenting with the spacing it was found possible to reduce the circuit Q and broaden the resonance so that this system, with a speaker of 63 cps free air cone resonance, smoothly extends to 50 cps without any peak at resonance.

The introduction of the acoustic resistance also has a strong effect upon air loading the speaker. This is very desirable in improving speaker damping and the magnitude of damping obtained may be judged from the amount of lowering in frequency of speaker resonance below the free air cone resonance. As shown in the impedance curve of Figure 5, the speaker resonance in the



IMPEDANCE CURVE
8 OHM 12" SPEAKER
IN R-J ENCLOSURE

Figure 5

R-J enclosure is 32 cps. as against 50 cps. for the same speaker in the bass reflex, Figure 2. It is believed that 32 cps. loaded speaker resonance, as against 64 cps. free air cone resonance, is considerably lower than can be achieved by other systems.

To show the performance of the system, the following demonstration was set up and performed. Figure 6 is a block diagram of the test setup. The amplifier (built by Audio Designs, Inc.) is a Williamson circuit employing two 5881 tubes in the output with 30 db of negative feedback and approximately 0.5 ohm of internal impedance. The two enclosures are as described in Figures 1 and 4. The same model 12" speaker was used in both enclosures. This speaker is a moderately priced ($25) popular hi-fi speaker with 8 ohms of impedance. The free air cone resonance as measured was 63 cps.

The microphone used was an Altec Lansing 21B with preamplifier and a 5" scope was used to observe the results.

The bass reflex and the R-J were placed side by side with the microphone on horizontal axis between both enclosures and on vertical axis of both speakers as shown in Figure 7. The comparison switch was thrown back and forth at various frequencies and the results noted. A direct comparison was thereby obtained between the performance of the enclosures under the same conditions.

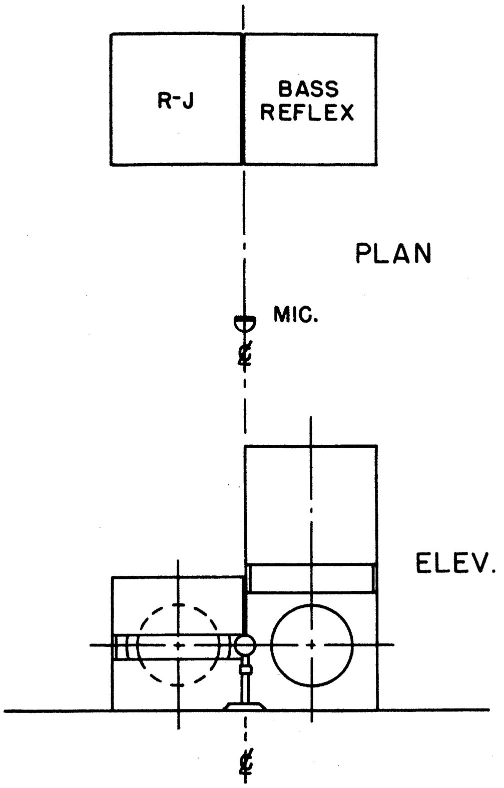


Figure 7

No equipment controls were operated except for the frequency control and the series of unretouched photographs of the oscilloscope screen shown as Figures 8 through 19 represents points on the sound-pressure frequency response curve under the conditions of test.

Figures 8 and 9 are of the bass reflex and the R-J respectively at 110 cps. Note equal sound pressure from both.

Figures 10 and 11 are taken at 84 cps. which is cabinet air resonance for the bass reflex and R-J as shown on impedance curves Figures 2 and 5 respectively.

Note the characteristic "boom" developed by the bass reflex as indicated by the large increase in output. As shown the R-J is only slightly increased and a slight reduction in frontal spacing

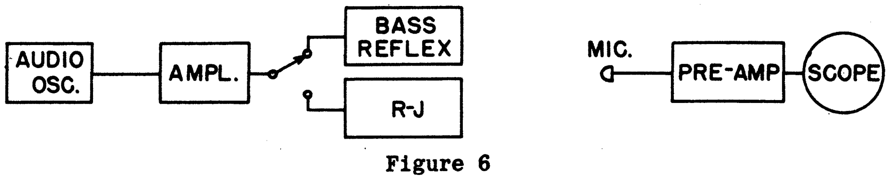


Figure 6

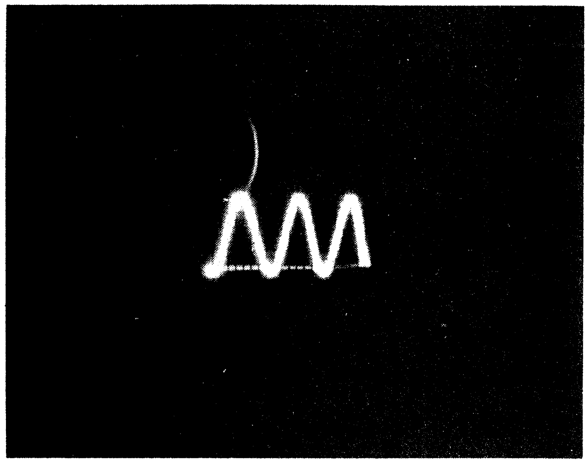


Figure 8

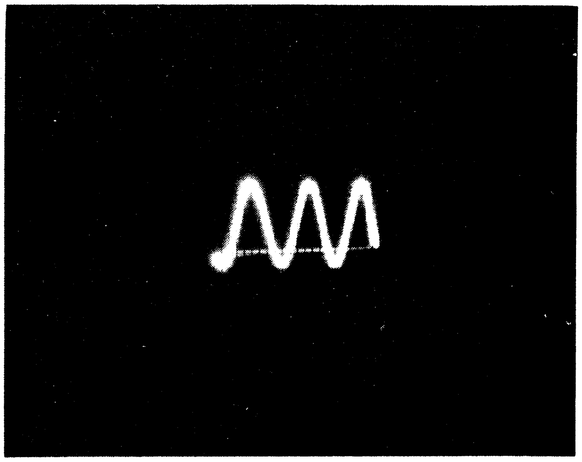


Figure 9

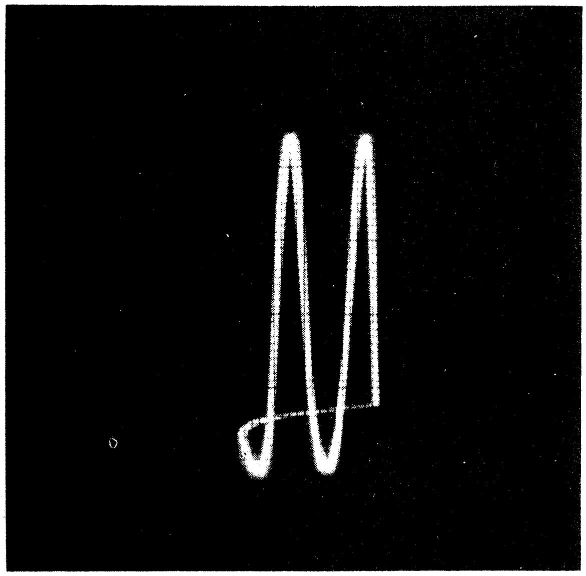


Figure 10

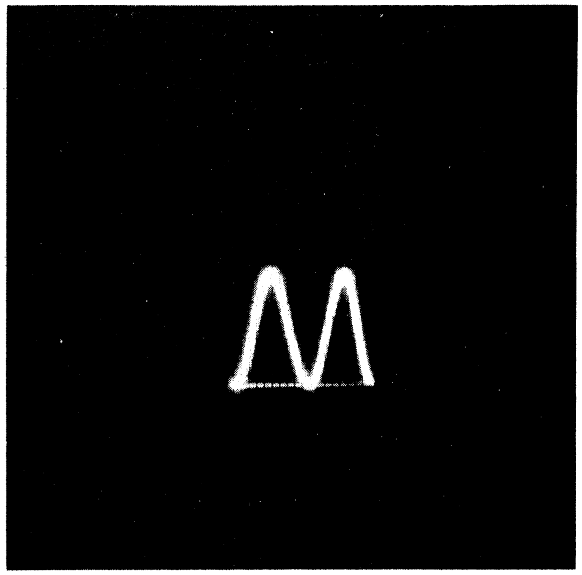


Figure 11

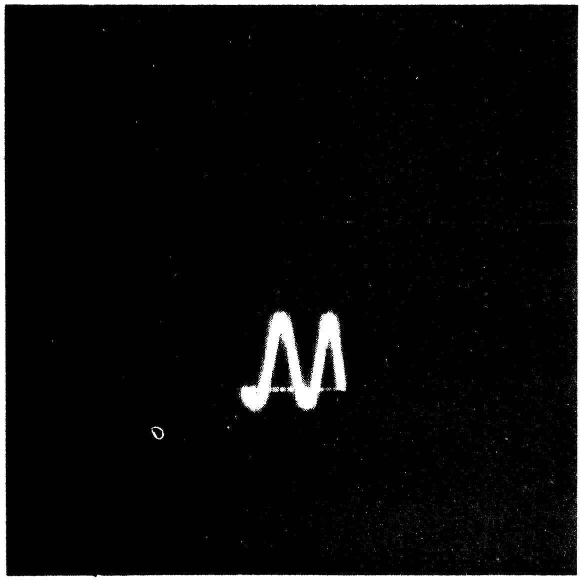


Figure 12

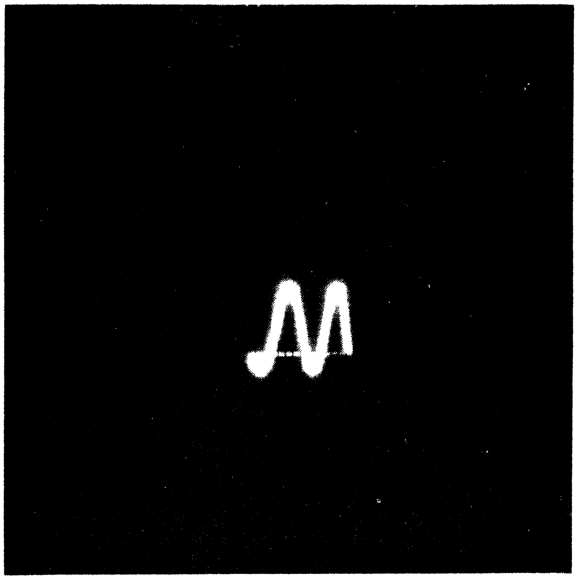


Figure 13

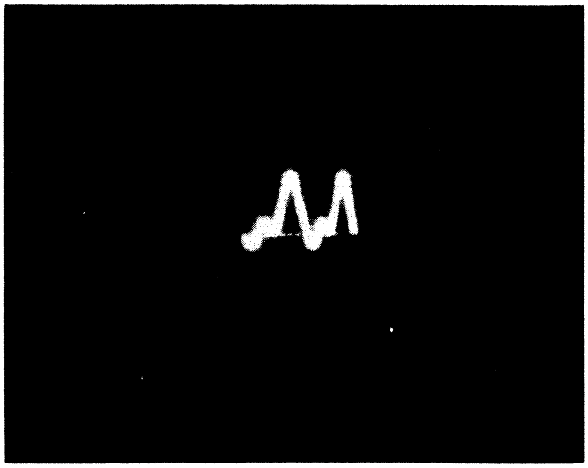


Figure 14

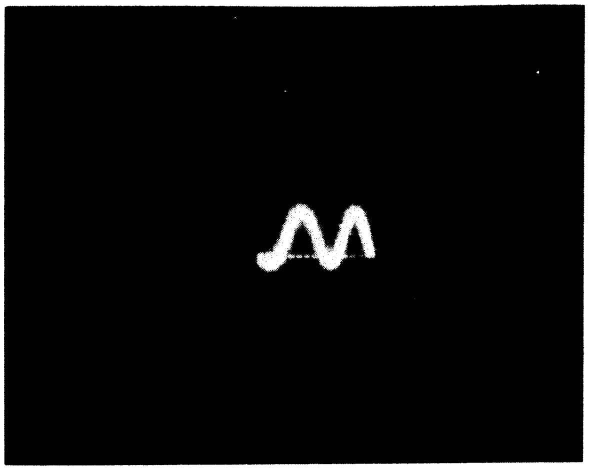


Figure 15

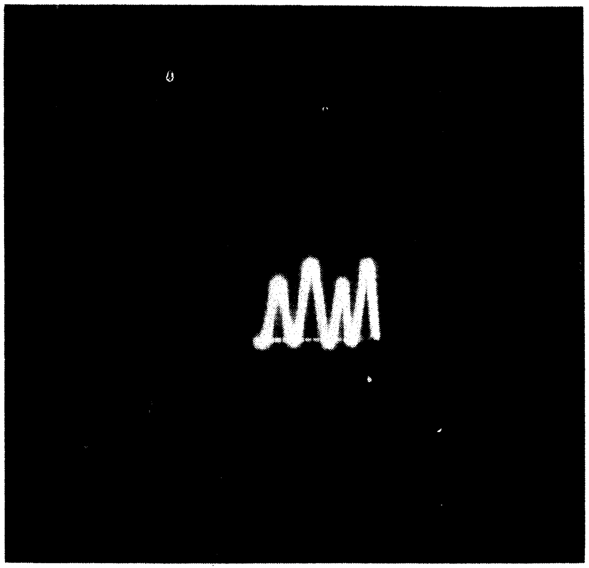


Figure 16

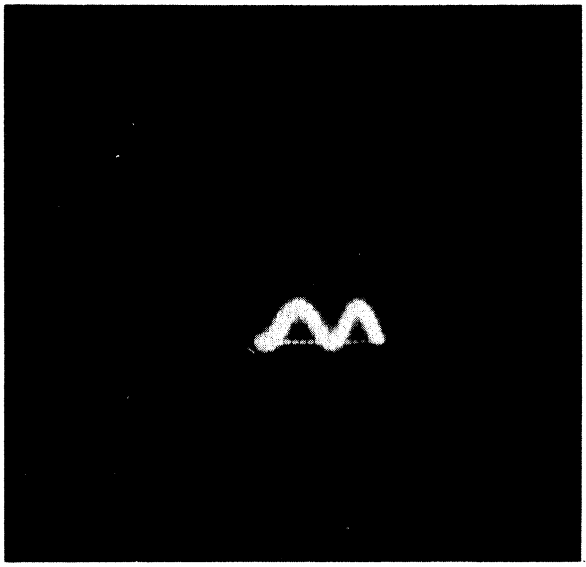


Figure 17

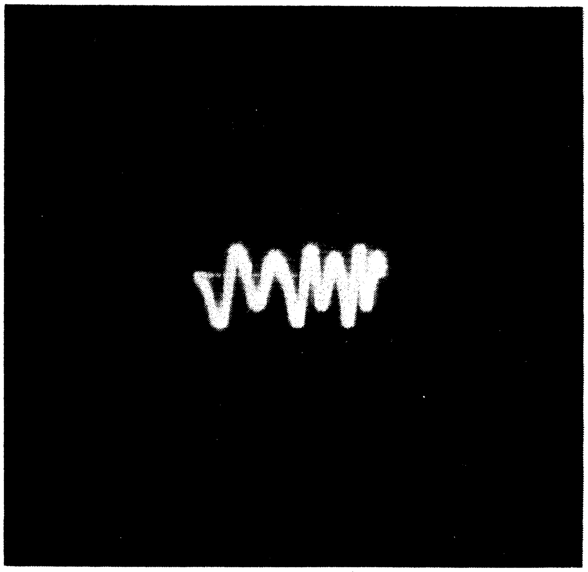


Figure 18

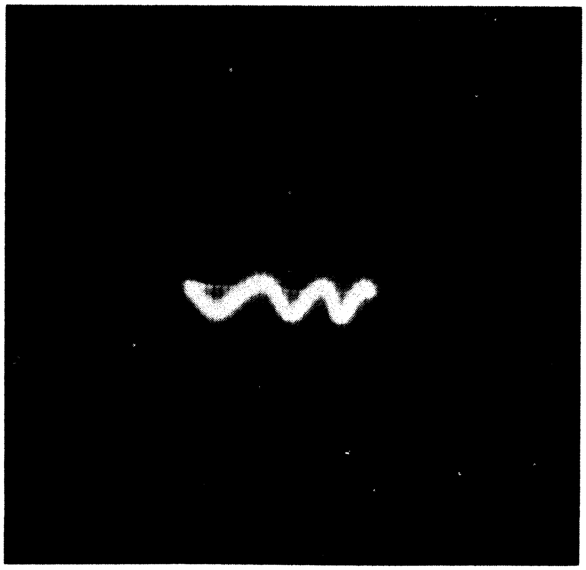


Figure 19

is required to take care of this.

Figures 12 and 13 are taken at 55 cps. Bass reflex and R-J maintain output equal to that at 110 cps.

Figures 14 and 15 are taken at 48 cps. The bass reflex is beginning to frequency double. The R-J is entirely fundamental.

Figures 16 and 17 are taken at 44 cps. The bass reflex is almost completely frequency doubled and the output consists almost entirely of 100% second harmonic distortion. The difference in pitch is plainly evident upon comparison switching, the bass reflex sounding one octave higher than true pitch. Another effect of this doubling is an increase in amount of apparent bass over true reproduction. The lack of fundamental tone will be particularly noticeable in the reproduction of low bass organ music where the octave rise in pitch becomes apparent, especially if choral singing or other high register notes occur in the same passage. In such case intermodulation of the upper register voices or notes becomes noticeable. The R-J, although somewhat down in output, still maintains the fundamental tone.

Figures 18 and 19 are taken at 32 cps. The bass reflex is still distorted while the R-J still maintains fundamental tone.

The ability of the R-J system to handle power without frequency doubling at the very low frequencies is due in main to the air loading on the speaker which the design of the enclosure effects. This loading is also beneficial in increasing the transient damping of the speaker and the power handling capacity. Transient damping which cuts down spurious speaker vibration or "hangover" after the signal has ceased may be demonstrated in a simple test. Keying the input of an audio oscillator to the system will produce a "click" on circuit make end, depending on whether the system is well damped or not, a "click" or "bong" respectively on the break. Particularly noticeable at frequencies near enclosure resonance, the bass reflex will go "click-bong" as the circuit is made and broken. The "click-bong" from an R-J under these conditions shows good transient response.

Conclusions:

1. Although based on a resonant principle, the R-J enclosure is an aperiodic system.

2. Response of the R-J with a 12", 63 cps. free air cone resonance speaker is smooth down to 50 cps. with usable but attenuated output down to 30 cps.

3. The R-J provides air loading instrumental in preventing frequency doubling and tripling and maintains fundamental tones with a 12" speaker down to 30 cps.

4. Good speaker damping and transient responses are inherent in the R-J enclosure design.

The demonstration was followed by playing various kinds of recorded music for comparison of both enclosures until the close of the meeting.

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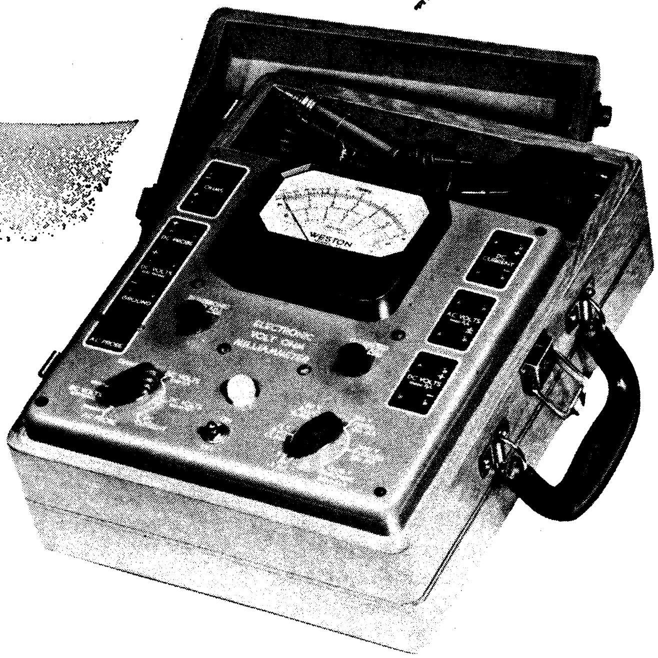

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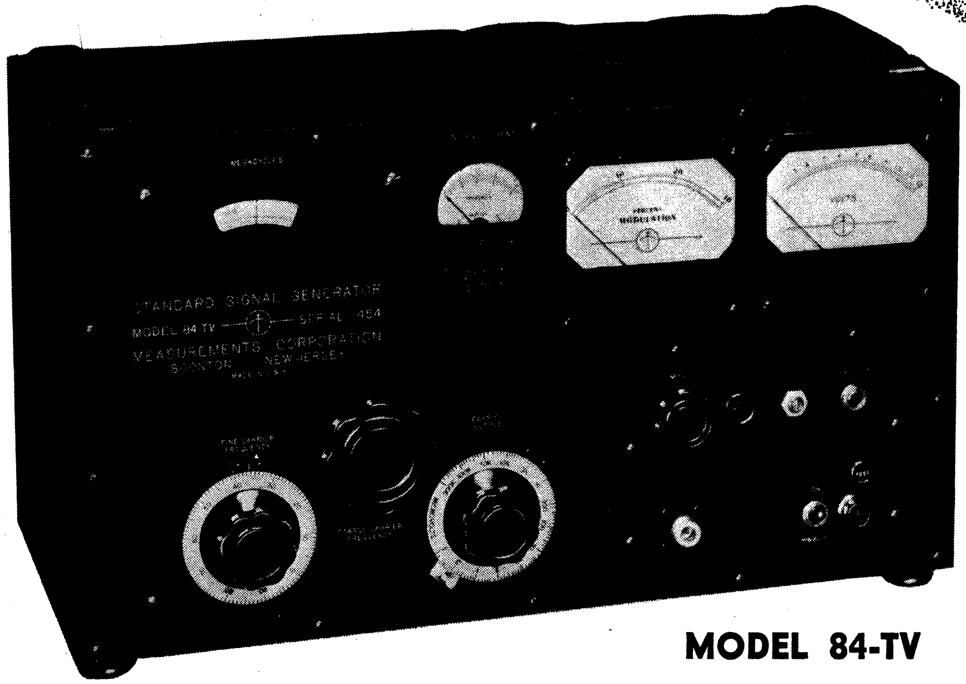

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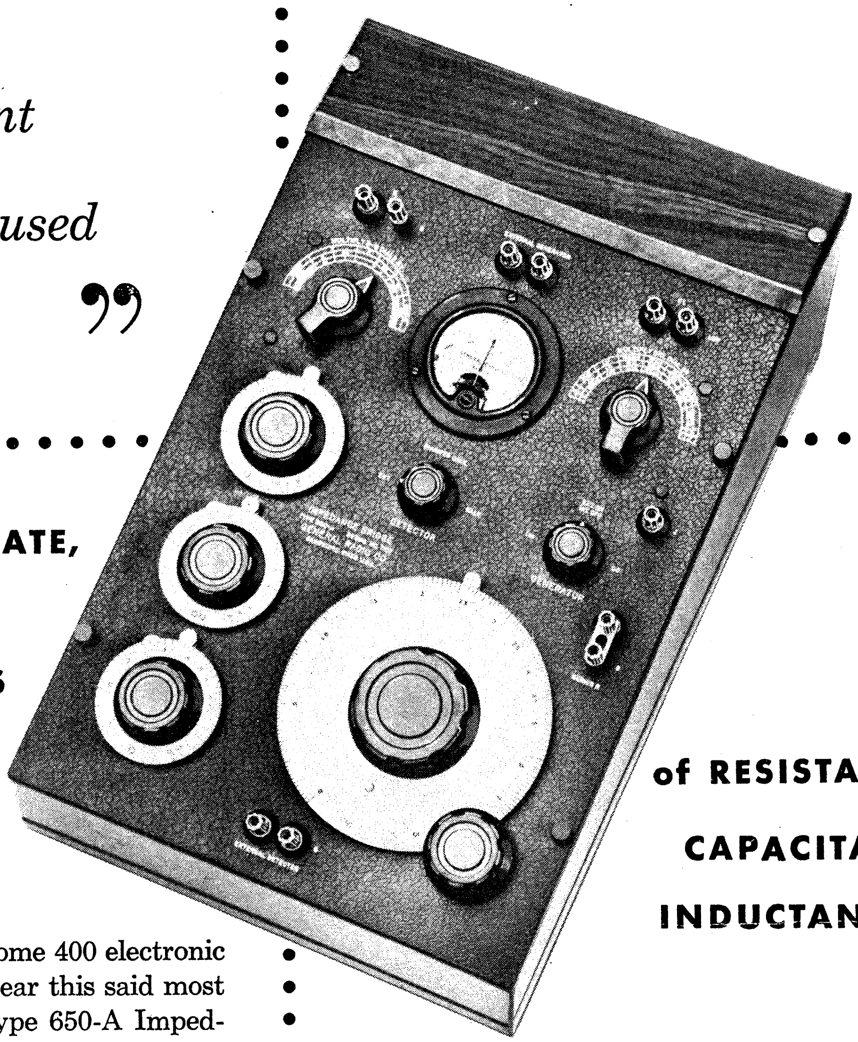

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