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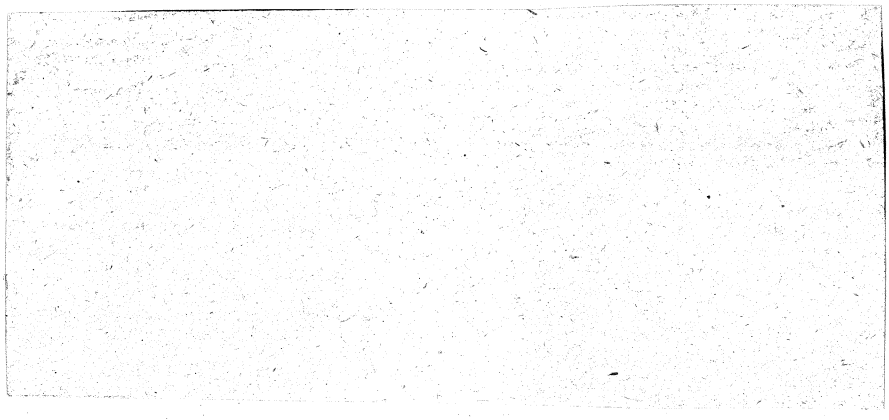
AUDIO DISTORTION IN RADIO RECEPTION

By Jerry Minter



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AUDIO DISTORTION IN RADIO RECEPTION

Observations of a Radio Engineer Who Believes That the Best Reproduction Is Exact Reproduction

BY JERRY MINTER*

THIS information represents the efforts of a hobby; it has no particular connection with the business interests of the Measurements Corporation or any other company. The criticisms given in this paper are presented with the hope that they will further the best interests of the radio industry.

It has been customary to specify only the amplitude response and harmonic distortion of audio systems. There are two other important forms of distortion: poor transient response and cross modulation. This paper is concerned with these latter two, since the author feels that ignorance of their importance is chiefly responsible for the failure of many so-called "high fidelity" audio system tests.

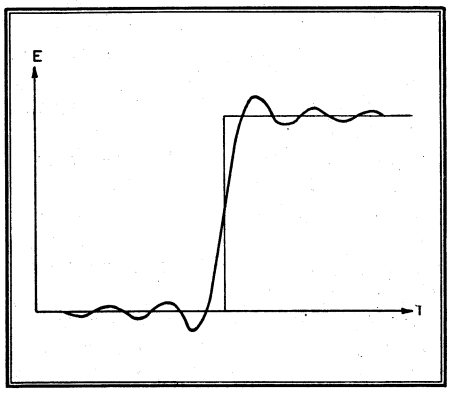


FIG. 1. EFFECT OF TOO SHARP CUTOFF

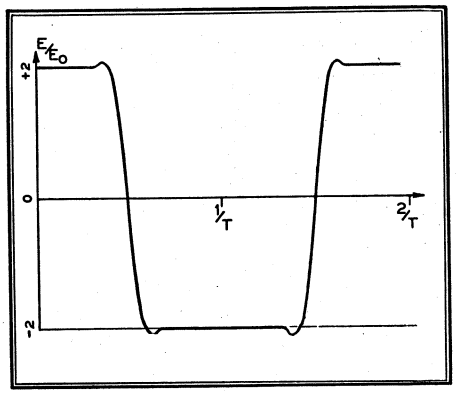


FIG. 2. CRITICALLY DAMPED RESPONSE

Transient Response ★ The early connection of amplitude band-width with fidelity of reproduction can probably be attributed to the Bell Telephone Company. The fallacy of neglecting transient band-width of the audio system arose because it was customary to assume that speech and music are made up of continuous tones. We all know that audible sounds have transient character, since they must start and stop sometime. The percussion instruments and staccato score on the brasses particularly demand good transient response.

A characteristic ringing at the cutoff frequency results from insufficient transient band-width or too sharp a cutoff in the amplitude band-width response. Fig. 1 indicates the transient response resulting from the application of a unit or step function to a network having too sharp an amplitude cutoff. The Bell Telephone Company ignored this as long as sufficient damping was present to prevent continuous oscillation (which is called singing). The public has been forced to accept such "Johnny-One-Notes" because the Bell Telephone Company knows best what's good for us.

The transient response can best be measured by applying a square wave of 3 to 10 kc. to the audio system. If the cutoff is gradual and well damped, no Johnny-One-Notes will be observed. Usually output transformer resonance will cause slight oscillations well above the audio range which can be neglected, if well damped. Negative feedback generally accentuates these damped oscillations

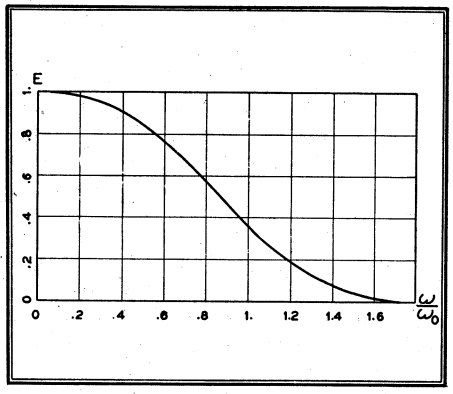
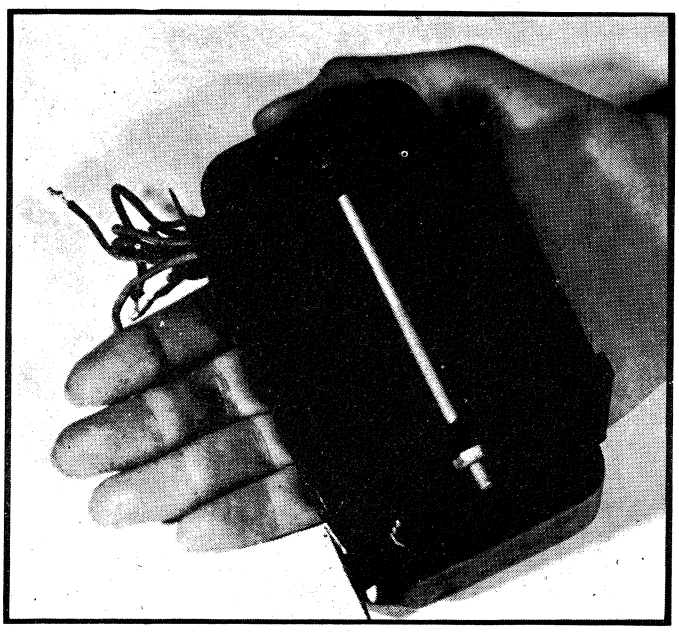
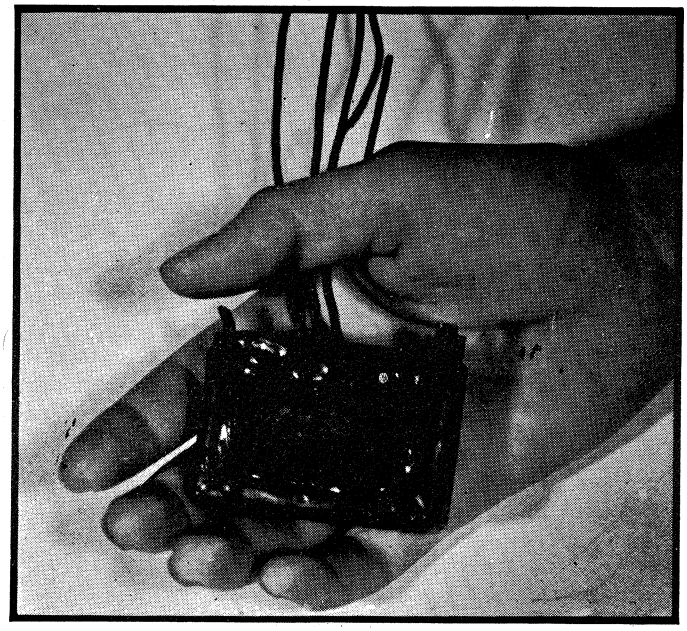


FIG. 3. NETWORK CHARACTERISTIC

*Chief Engineer, Measurements Corporation, Boonton, N. J. A paper delivered at the December, 1944 meeting of the Radio Club of America, New York City.



ADEQUATE TRANSFORMER COSTS $1.79, WEIGHS 5½ LBS.



79¢ OUTPUT TRANSFORMER FROM RADIO SET, ¾ LB.

which may become continuous at a superaudible frequency and actually overload the amplifier.

Fig. 2 is taken from Kallmann's "Transversal Filters", *Proceedings of the Institute of Radio Engineers*, July, 1940. This represents a critically damped response of a network which has the optimum amplitude characteristic shown in Fig. 3. This curve represents the maximum rate at which the amplitude response can be allowed to drop without introducing ringing or Johnny-One-Notes.

Further acknowledgment of the importance of transient band-widths has come from Dr. Hanson in his recent paper before the 1944 National Electronics Conference in Chicago.

Emphasis is now placed on transient response in television applications, wherein it is obviously of great significance. However the principles apply with equal force to faithful audio reproduction and are perhaps the number one reason why the American public demands the tone control to cut out the Johnny-One-Notes created by our *faithful servant* the Bell Telephone System.

The advent of Frequency Modulation with its inherent excellent transient response, has permitted my personal observation of sound reproduction free from these effects. The simplicity of direct FM relay offers great promise for reducing this and other forms of audio distortion, without the great expense involved in the installation and maintenance of equally satisfactory long lines and repeaters.

Cross-Modulation Distortion ★ Cross-modulation distortion is defined herein as the generation of sum and difference frequencies when two or more tones are applied simultaneously to a system. Since these sum and difference frequencies do not necessarily bear any harmonic relation to the original tones, the resultant reproduction has a rather confused or muddled background accompanying it.

A test for the presence of such distortion is to note whether a solo instrument in the medium register must have only a soft or subdued accompaniment in order to sound clear. If rather heavy orchestral accompaniment tends to mask the solo instrument, this is probably due to cross-modulation in the system.

Another striking example is presented when the church choir is accompanied by heavy organ bass. Few systems are capable of justice to this combination because of cross-modulation defects.

Such distortions arise chiefly in iron cored transformers and reactors in the system. It has been a common experience for many people to say that FM does not give as much bass response as AM. I have personally observed this effect, since in the New York area several networks originating suitable program material frequently transmit simultaneously via both AM and FM. Invariably the AM seems to have more bass.

Since our Company manufactures a standard signal generator having AM type modulation, I decided to test its modulation system for cross-modulation effects. Fig. 4 indicates the connections and the resulting spectrum for 30% 50-cycle modulation. Only two sum and difference frequencies of 950 and 1,050 cycles are produced about 1,000 cycles, and their magnitude is less than 10 millivolts or 1%. Fig. 5 gives the spectrum for 40% 50-cycle modulation. It can be seen that a whole family of sidebands have been created about 1,000 cycles. Fig. 6 indicates about fifty different sum and difference frequencies for a 50% 50-cycle modulation.

The Model 65-B signal generator uses some negative feedback, and the frequency response is flat within 1 db or 10% to 50 cycles. It can be seen that only 10% of the second harmonic is present on Fig. 6. This amount of second harmonic is scarcely perceptible at such a low frequency because of the harmonic generation present in the human ear itself. The resultant spectrum about 1,000 cycles is definitely noticeable and tends to create the impression of much heavier bass because the human ear tends to react in a somewhat similar manner, and our senses cannot differentiate between synthetic and natural cross-modulation.

In properly designed FM systems, the cross-modulation is much less, since it is not necessary to use iron-core reactors. Hence the false impression of less bass. The absence of cross-modulation results in clean, distinct reproduction. One no longer shudders when the pipe organ hits a heavy bass note, for the choir seems to stand out as tho a screen or curtain had been drawn aside.

I issue a challenge to the AM broadcasters to measure and remedy the cross-modulation distortion in their transmitters.

I also invite the Bell Telephone Company to measure the cross-modulation on their transmission lines and repeaters between even Philadelphia and New York, not to mention Los Angeles and New York.

No wonder the American public doesn't like *high fidelity radios*. I hold in my hand the output transformer removed from a popular make of home receiver. This particular receiver sold for several hundred dollars, and its manufacturer has spent large sums on acoustical improvement but completely neglected the vital output transformer. Fig. 7 shows the cross-modu-

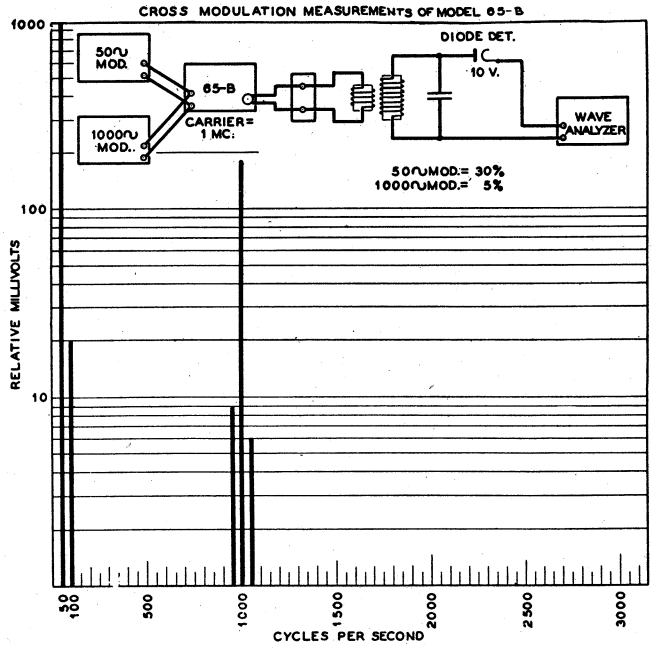


FIG. 4. 30% 50-CYCLE MODULATION AND 5%, 1000 CYCLES

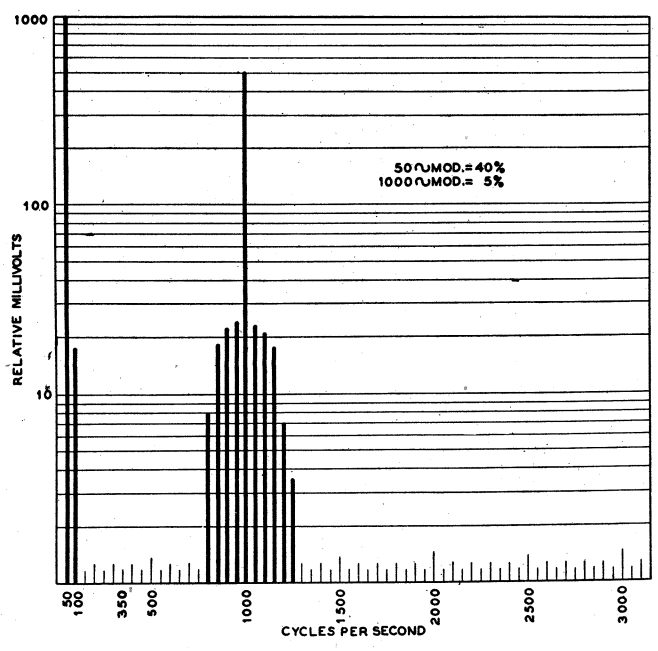


FIG. 5. 50-CYCLE MODULATION INCREASED TO 40%

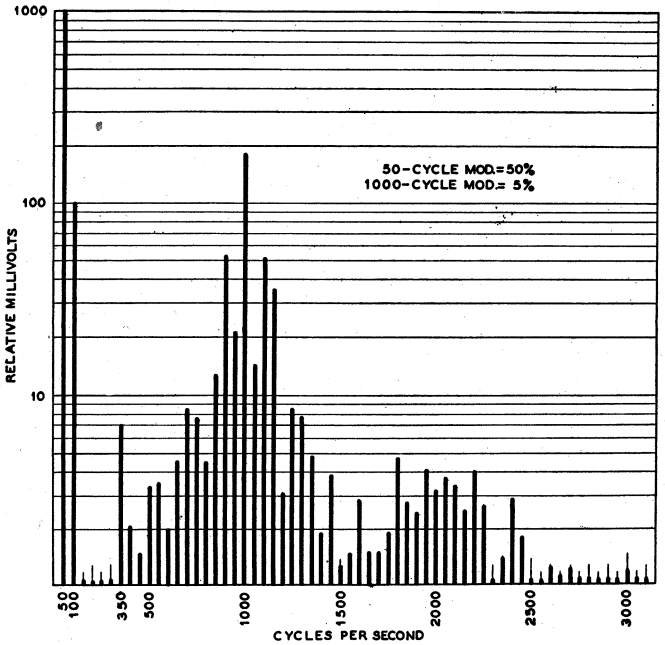


FIG. 6. 50-CYCLE MODULATION INCREASED TO 50%

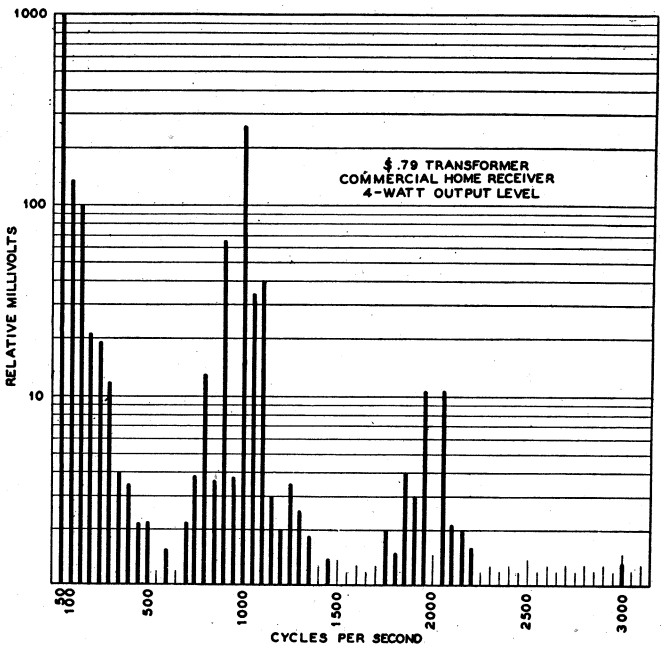


FIG. 7. CROSS-MODULATION IN COMMERCIAL RADIO SET

lation spectrum of this particular receiver with a *resistance* load in place of the speaker. The manufacturer used pentodes without feedback, and I didn't bother taking any overall acoustical data. You will note that the 79¢ output transformer yields a generous spectrum. This data was taken at a 4-watt level, since the pushpull 6V6 amplifier was not capable of supplying more power without serious harmonic distortion.

Fig. 8 was taken after a larger output transformer was substituted. This output transformer could probably be made for $1.79, altho this particular transformer was designed for 25-cycle operation as a power transformer. The center-tapped, high-voltage winding was used for the plate-to-plate winding with the center tap for B+, while the 6-volt filament winding was used for the speaker voice-coil winding. About 8 db of negative feedback was applied after the coupling capacitors in the audio has been increased from .005 to .1 mfd. This feedback helped damp the speaker by lowering the effective output impedance of the amplifier. More feedback would have been desirable if enough gain were available; however, this would have necessitated adding an extra audio amplifier. The 8 db of feedback has practically nothing to do with the improvement in cross-modulation distortion. Just using more iron with less flux density in the output transformer has done the trick. Incidentally the receiver sounds improved beyond expectations.

It may be noted here that John K. Hilliard reported in his article in the December, 1941 *Proceedings of the IRE* that 2% cross-modulation distortion was not objectionable. It can be seen that the spectrum of Fig. 8 just meets this requirement. So much for the $1.00 improvement. Let us hope that postwar receiver manufacturers will at least do this one thing in their more expensive models. Note that the improvement will be most noticeable in FM receivers when tuned to a program originating in the station's own studios and not transmitted via telephone lines.

Good Audio Practice ★ Necessary power output is all embracing, since this determines the amount of iron to be used in the output transformer, size of loudspeaker, acoustical enclosure, etc. Undoubtedly a 5-watt *average* electrical level into a good reproducer is ample for most homes with a reasonably low background or ambient noise level. This does not mean that the amplifier output is limited to 5 watts, but rather that the audio amplifier should

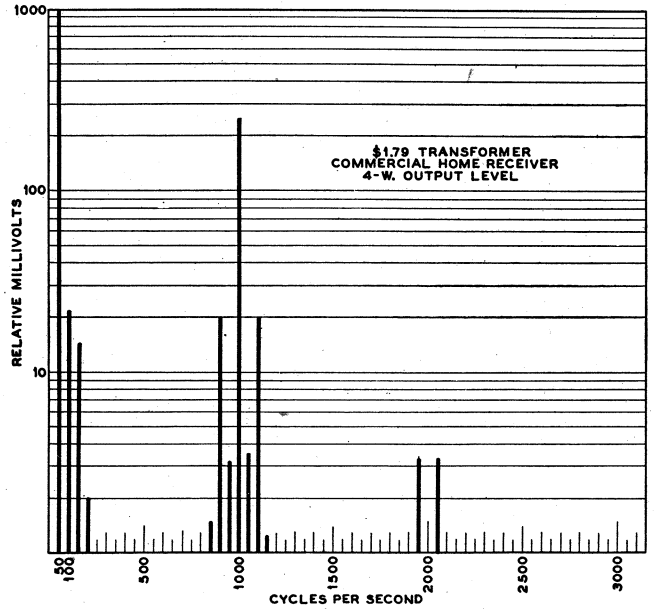


FIG. 8. RESULTS WITH AN ADEQUATE OUTPUT TRANSFORMER

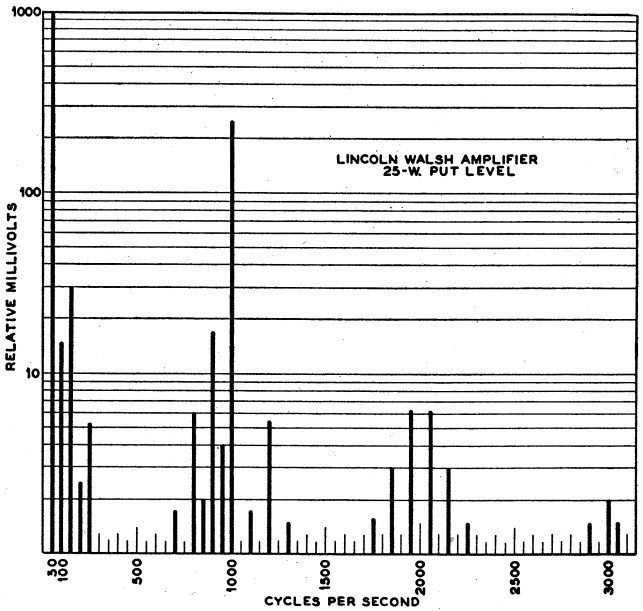


FIG. 9. L-W AMPLIFIER AT 25-WATT OUTPUT LEVEL

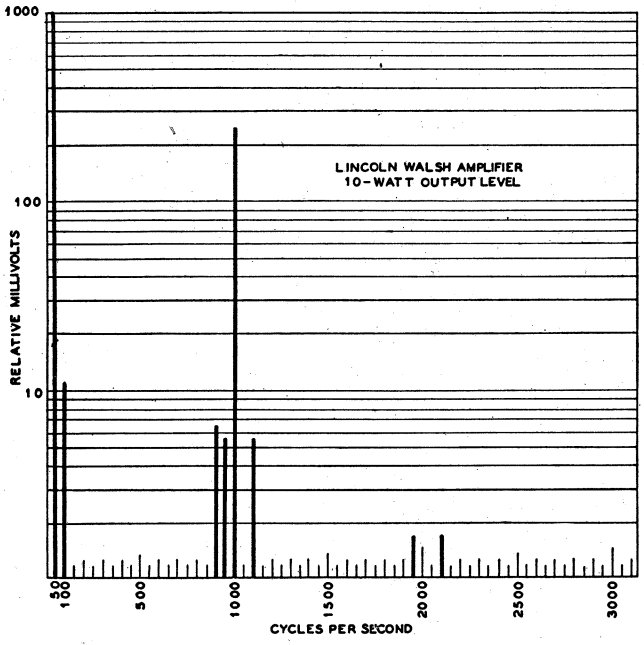


FIG. 10. L-W AMPLIFIER AT 10-WATT OUTPUT LEVEL

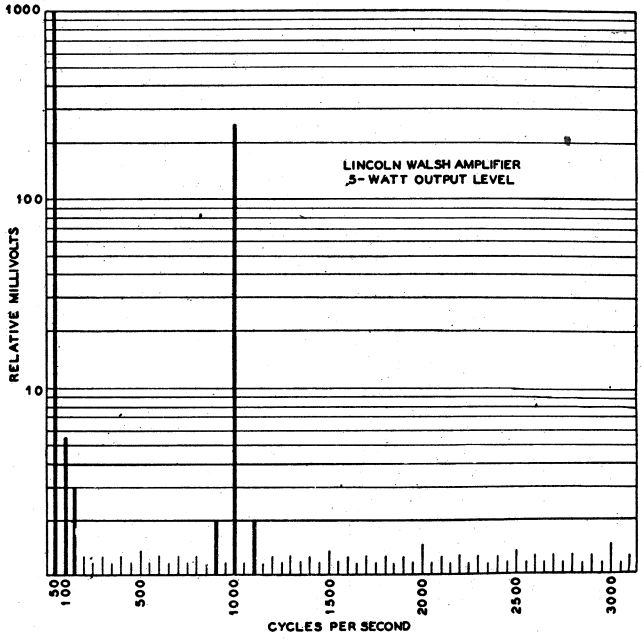


FIG. 11. L-W AMPLIFIER AT 5-WATT OUTPUT LEVEL

be capable of supplying in the neighborhood of 20 watts to take care of the peak power requirements which occur frequently in music. The peaks are of short duration and can be efficiently accommodated by an arrangement developed by Lincoln Walsh. Fig. 9 indicates the cross-modulation spectrum into a resistance load from a Walsh amplifier at the 25-watt level. At this level the two type 2A3 tubes are drawing rather heavy current and practically operating class B, but the output transformer is not generating cross-modulation components as high as 2%. Incidentally the output transformer in the Walsh amplifier resembles in size a 100-watt 60 cycle power transformer.

The Walsh amplifier contains a cathode follower driver and automatically adjusts the bias of the 2A3 tubes which allows them to operate as fixed bias class A output tubes up to about 10 watts. Fig. 10 shows the distortion spectrum at the 10-watt level. Fig. 11 shows the results with the Walsh amplifier at 5 watts. It can be seen that the cross modulation products are less than 2 millivolts or 0.2%.

Of course, it is necessary to convert the electrical output into acoustical sound pressure, and Fig. 12 indicates the overall sound pressure spectrum with 5 watts fed into an HY-12-12 speaker with a QP-5 tweeter. The microphone was placed about 18 ins. directly in front of the speaker which was operated in my home as normally used. It is interesting to note that cross-modulation is present in the speaker, but the components do drop off rather rapidly with increasing frequency. Above 550 cycles, they are less than 2%.

Since natural resonance of the HY-12-12 cone occurs around 45 to 50 cycles, another set of data was taken with 80 cycles substituted for the 50-cycle tone. This acoustical output spectrum is plotted in Fig. 13. It can be seen that the maximum overall distortion amplitude is less than 3%.

It is the consensus of most who have visited my home and listened to good, direct studio FM programs that faithful wide-range audio is truly different. Many have remarked that this doesn't sound like a radio set. Some say that it sounds like the orchestra that they may have heard in Radio City Music Hall or Carnegie Hall, and then I begin to realize that the average citizen has never really heard natural reproduction by radio. Since I have had approximately ten years experience as a musician, *natural* reproduction does not sound unreal to me. Re-

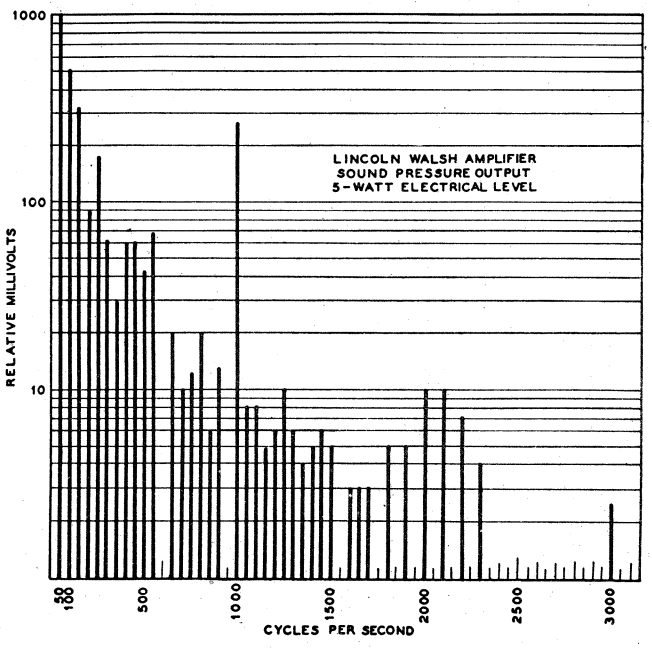


FIG. 12. ACOUSTICAL SOUND PRESSURE AT 5-WATT LEVEL

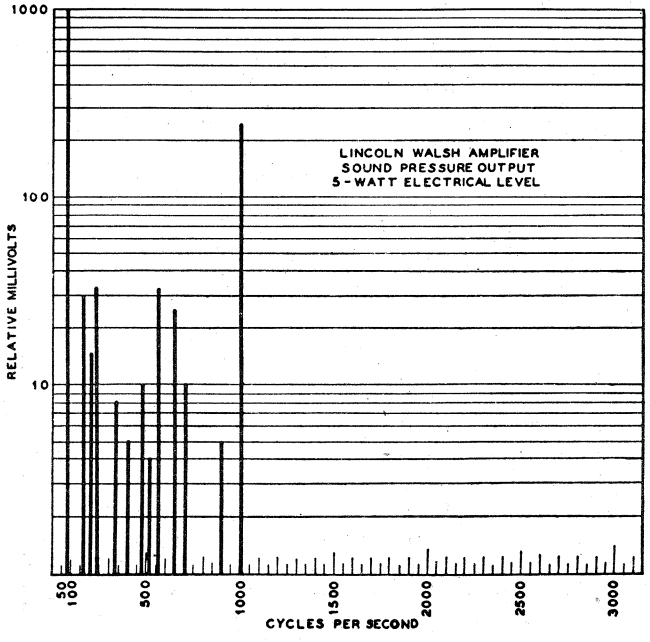


FIG. 13. 80 CYCLES SUBSTITUTED FOR 50 CYCLES USED IN FIG. 12

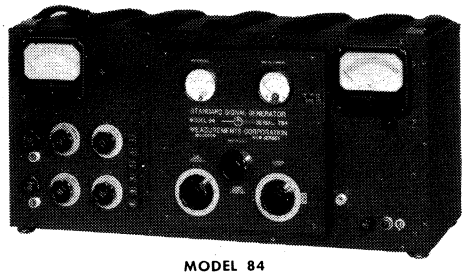
gardless of the Bell Laboratories, CBS, or NBC, with their fact-finding tests to contrary, I side with Major Armstrong and say: give the public wide-range audio up to 15,000 cycles. Better receivers will be accepted because there will be some reason to want them, if suitable programs are provided by the radio stations and their associated networks. Even programs involving no music, such as Abie's Irish Rose, become much more enjoyable with a wide range system. One gets a feeling of *presence* — after a moment of scientific reflection, this sensation of presence is natural, because the higher frequencies are instinctively associated with nearby sounds since the higher frequencies are attenuated more rapidly as the distance is increased.

Speaker mounting and baffle design is truly a problem. My own personal preference is the result of many trials and listening tests. I use a large, well-braced, closed cabinet having some sound absorbing felt directly behind the speaker to remove high frequency reverberation. The bottom of the cabinet is formed by the floor itself, and the resulting floor vibration is very effective in producing natural sounding bass tones.

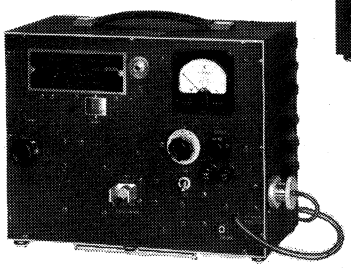
It is well known that one really *feels* low notes. At the higher sound levels, the ear does cross-modulate as previously mentioned, and this is interpreted as the sensation of bass. In November, 1941 Mr. Sheppard presented a paper on Synthetic Bass before the I. R. E. Rochester Fall Meeting which demonstrated how effectively artificial cross-modulation produced by vacuum tubes and associated circuits could simulate actual bass response. The thing missing in his demonstration was the physical feeling that always accompanies such heavy bass response. If it were possible to use such a synthetic system in conjunction with a suitable direct-connected, floor-driving system, very effective bass sensations could probably be produced without the need for such large console cabinets. Such synthetic bass cross-modulation should necessarily be confined to the region below 500 cycles where it would not produce such objectionable masking as the usual type of cross-modulation mentioned herein.

In conclusion may I suggest that you test out for yourselves the authenticity of the statements and conclusions advanced in this paper. Fortunately, in the New York area it is possible to secure FM program material of sufficient range and quality to bear out the above conclusions.

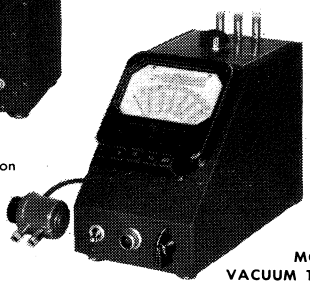
Laboratory Standards



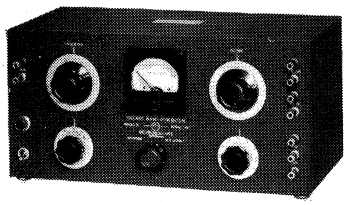
MODEL 84
U.H.F. STANDARD SIGNAL GENERATOR
300 to 1000 megacycles, AM and Pulse Modulation



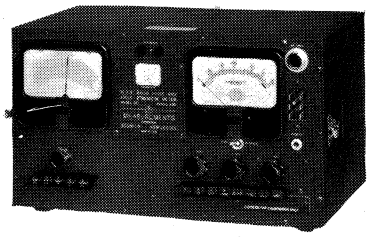
MODEL 78-B STANDARD SIGNAL GENERATOR
Two Frequency Bands between 15 and 250 megacycles



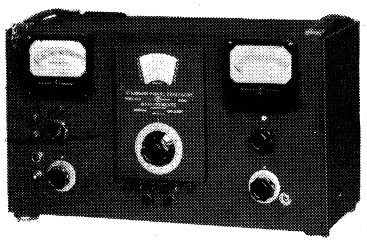
MODEL 62
VACUUM TUBE VOLTMETER
0 to 100 volts AC, DC and RF



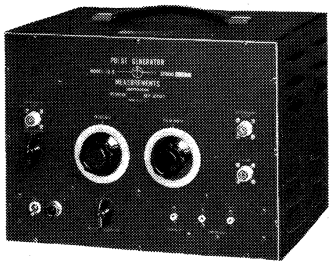
MODEL 71 SQUARE WAVE GENERATOR
5 to 100,000 cycles
Rise Rate 400 volts per microsecond



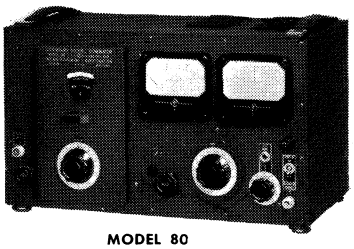
MODEL 58 U.H.F. RADIO NOISE AND FIELD STRENGTH METER
15 to 150 megacycles



MODEL 65-B
STANDARD SIGNAL GENERATOR
75 to 30,000 kilocycles
M.O.P.A., 100% Modulation



MODEL 79-B PULSE GENERATOR
50 to 100,000 cycles
0.5 to 40 microsecond pulse width



MODEL 80
STANDARD SIGNAL GENERATOR
2 to 400 megacycles
AM and Pulse Modulation

Standards are only as reliable as the reputation of their maker.

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