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RECENT DEVELOPMENTS IN SUPERHETERODYNE RECEIVERS*

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Summary—*Major electrical elements of a modern superheterodyne receiver-tuned radio-frequency amplifier, intermediate frequency amplifier detector and audio-frequency amplifier—are briefly discussed in light oj recent developments. A practical automatic volume control is described. Curves illustrating the major performance characteristics of the receiver are shown.*

Introduction

In the past four years broadcasting conditions have changed so greatly that receivers which were giving satisfactory service at the beginning of that period are now obsolete. The steady increase in the number of broadcasting stations and the advent of the super-power stations have imposed exacting selectivity requirements on modern receiving sets. The congested condition of our cities with their numerous apartment buildings and the resultant lack of antenna facilities have likewise created the demand for receivers having sufficient sensitivity to permit the use of either a small indoor or outdoor antenna. The marked improvement in the quality of radio programs and their transmission and the development of the moving coil type of loudspeaker have made the fidelity of present day receivers a consideration of major importance. The superheterodyne receiver is particularly adapted to meet these modern broadcasting conditions. It is the purpose of this paper to discuss some recent developments in this type of receiver.

General

The conventional tuned radio-frequency receiver has two main electrical elements, namely, the tuned radio-frequency amplifier and the detector and audio-frequency amplifier. The modern superheterodyne receiver has both these elements and, in addition, an intermediate frequency amplifier with associated

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frequency converting oscillator and detector. The high amplification and great selectivity of this intermediate frequency amplifier largely account for the remarkable performance of the superheterodyne receiver.

The ease of obtaining high amplification and selectivity in an intermediate frequency amplifier is chiefly due to the low frequency used and to the fact that the characteristics of such an amplifier are independent of the broadcast frequency to which the set is tuned. At these lower frequencies by the use of coupled circuits it is possible to obtain the so-called band-pass filter selectivity characteristics.

Improved radio-frequency circuits and the use of a higher intermediate frequency have contributed a considerable reduction in hiss and extra responses common to previous superheterodyne receivers.

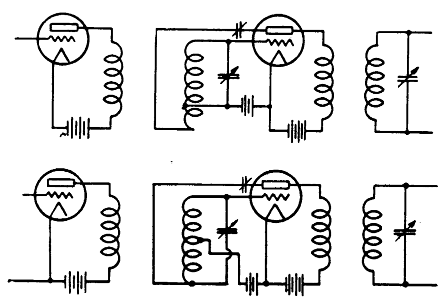

Fig. 1

The adjacent channel selectivity and the fidelity of broadcast receivers using a given number of tuned circuits are so related that it is impossible to increase either of these characteristics beyond certain limits without a corresponding sacrifice in the other.

A radio receiving set may be designed using four tuned circuits which will have a better adjacent channel selectivity than an eight tuned circuit receiver which is designed for good fidelity. The four tuned circuit set will be lacking in fidelity due to the attenuation of the side bands, and will also have less selectivity for stations separated by 30 kc or more. If the four tuned circuit set is made to equal the fidelity of the eight tuned circuit set, it will be inferior in selectivity in every way.

The use of broader radio-frequency and intermediate frequency circuits in connection with a negatively biased detector capable of high voltage outputs and a single stage of audio-frequency amplification has contributed a major improvement in the fidelity of the modern superheterodyne receiver.

The incorporation of a practical automatic volume control has eliminated the necessity of repeated adjustment of the volume control both when tuning from distant to local stations or vica versa, and when receiving stations whose field strength is varying periodically.

Radio-Frequency Amplifier

The selectivity of a well designed superheterodyne receiver for eliminating local stations is chiefly determined by the selec-

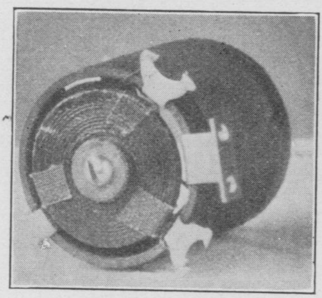

Fig. 2

tivity characteristics of the intermediate frequency amplifier. There are, however, a few exceptions; for example, if no radio-frequency selectivity is employed, two signals of equal strength differing in frequency by twice the intermediate frequency will be received with equal intensity with the heterodyne oscillator tuned midway between them. In addition to this objectionable response, harmonics of the oscillator heterodyning undesired signals are likely to cause interference. An input circuit tuned to the signal it is desired to receive reduces the possibility of interference to some extent, but in the vicinity of powerful broadcasting stations more than one tuned circuit is necessary.

The usual type of tuned radio-frequency transformer consisting of a few turns in the plate circuit of the amplifier tube coupled to the tuned secondary gives a selectivity characteristic which is much sharper at the low-frequency end of the broadcast range than at the high. In fact, it is usually so sharp that two or three stages of this type of amplification results in considerable reduction of the high modulation frequencies. A transformer of this type designed for good selectivity at the high-frequency end of the range will usually be lacking in amplification at the low-frequency end of the range.

A new radio-frequency system has been developed which overcomes most of the objections to the type just described. It provides much more uniform selectivity and amplification without resorting to some mechanical means of varying the coupling with frequency. The only difference between the new transformer and the old is in the type of primary used. Where the primary for the old type of radio-frequency transformer was

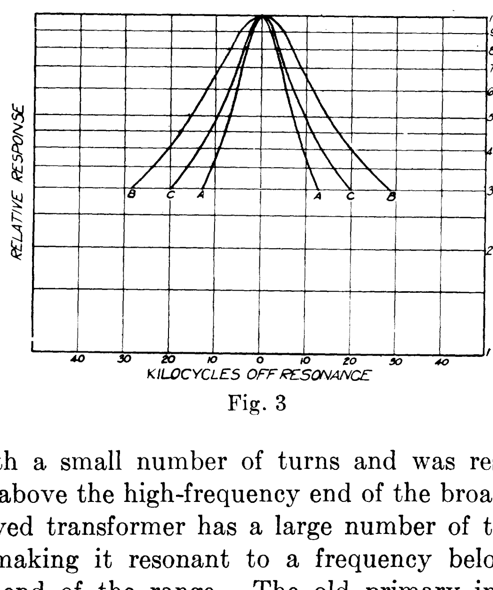

Fig. 3

wound with a small number of turns and was resonant to a frequency above the high-frequency end of the broadcast range, the improved transformer has a large number of turns on the primary, making it resonant to a frequency below the low-frequency end of the range. The old primary increased the effective secondary resistance at the higher frequencies where it was normally too great for good selectivity. The new primary increases the effective secondary resistance at the low-frequency end of the range where it is normally too low for high fidelity.

Since the primary is resonant at a frequency below the broadcast range, the amplification is increased at the low frequencies and reduced somewhat at the high, making it uniform over the range.

In order to realize the normal amplification of high inductance primary transformers, some means must be used to compensate for the effect of the grid to plate capacity. This is due to the primary being tuned to a lower frequency than the secondary, thus giving the plate circuit capacitive reactance. The voltage fed back through the tube capacity is therefore of such a phase as to oppose the applied grid voltage and will reduce this voltage to a fraction of its normal value. Either of the methods shown in Fig. 1 may be used to overcome this effect. If the feed-back capacity is made too large, it is possible to make the circuit oscillate.

Fig. 2 shows one form of a transformer of the high inductance primary type. Curves *A*, *B*, and *C*, Fig. 3, are resonance curves taken at 600 kc showing the effect of the two types of primaries

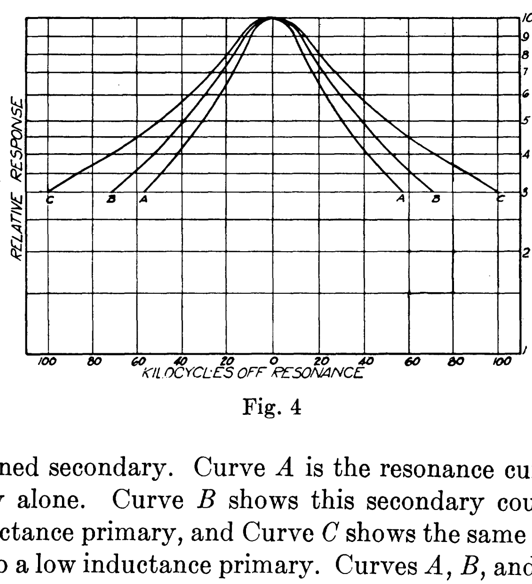

Fig. 4

on the tuned secondary. Curve *A* is the resonance curve of the secondary alone. Curve *B* shows this secondary coupled to a high inductance primary, and Curve *C* shows the same secondary coupled to a low inductance primary. Curves *A*, *B*, and *C*, Fig. 4, are similar curves taken at 1400 kc. Fig. 5 shows the amplification curve for a complete stage of radio-frequency amplification using a high inductance primary transformer and a UY-227 tube.

Intermediate-Frequency Amplifier

In past superheterodyne receivers the intermediate frequency has usually been in the neighborhood of 40 or 50 kc. This choice resulted from the ease of obtaining a stable amplifier for a frequency in this region having the necessary amplification and the desired selectivity characteristics. Now, however, another important factor must be considered in the choice of an intermediate frequency.

From Fig. 6, showing the selectivity of the two tuned radio-frequency circuits, it is noted that the higher the intermediate

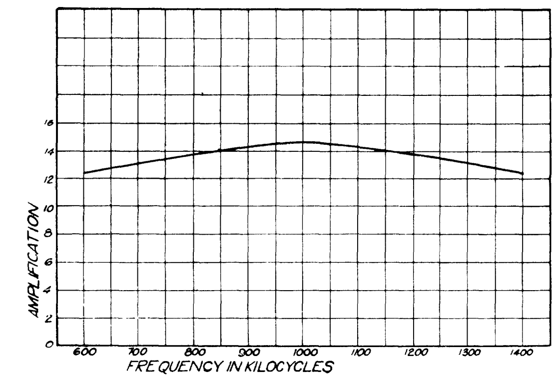

Fig. 5

frequency used the less the possibility of encountering interference from stations separated by twice the intermediate frequency. From the curve it will be seen that this interference for a 40-kc amplifier would be 350 times that for a 400-kc amplifier and 60 times that for a 200-kc amplifier.

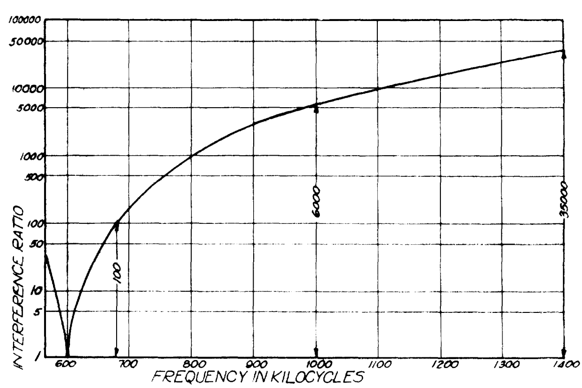

Fig. 6

An intermediate frequency of 180 kc was finally chosen as the best compromise between amplification, stability, selectivity, and undesired responses.

With an intermediate frequency of 180 kc and the oscillator tuned to a higher frequency than the radio-frequency circuits, it will be seen that broadcasting stations separated by twice the intermediate frequency will not produce interference at frequencies above 1140 kc. The selectivity of the radio-frequency system at the high frequencies is therefore not as important in this receiver as at the low frequencies.

Both the primary and the secondary of the three transformers used in the 180-kc amplifier are tuned, and the two windings are so coupled as to give a broad top resonance characteristic. Curve *A*, Fig. 7, is for a single stage of the inter-

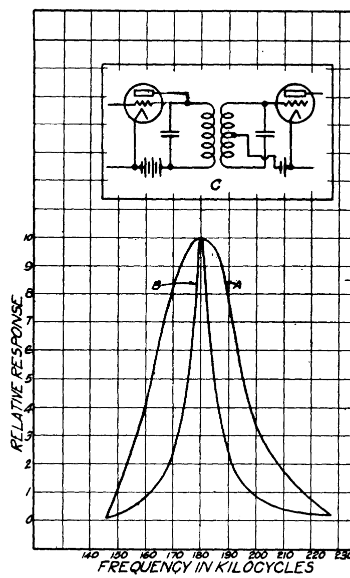

Fig. 7

mediate-frequency amplifier as shown in circuit *C*, having the proper magnetic coupling between the primary and secondary Curve *B* shows the combined characteristic of the primary and secondary used as separate tuned circuits with vacuum-tube coupling between them. Such a characteristic would be obtained if these individual circuits were used separately in a cascade amplifier. These two curves indicate the improvement that can be obtained by the use of coupled circuits, provided the losses in the individual circuits can be kept reasonably low.

The overall resonance curve for the intermediate-frequency amplifier is shown in Fig. 8. The approximately ideal band-pass filter characteristics of this amplifier should be noted, the band width at 50 per cent peak amplitude being 16 kc while at 1 per cent peak amplitude it is only 40 kc.

The three transformers are each mounted in individual metal containers which serve both to protect the transformer and shield it electrically. The primary is tuned by a compact fixed condenser, and the secondary by a small adjustable condenser which permits accurate alignment of the three transformers.

The balancing, primary, and secondary tuning condensers are mounted on a small piece of bakelite to which are also riveted

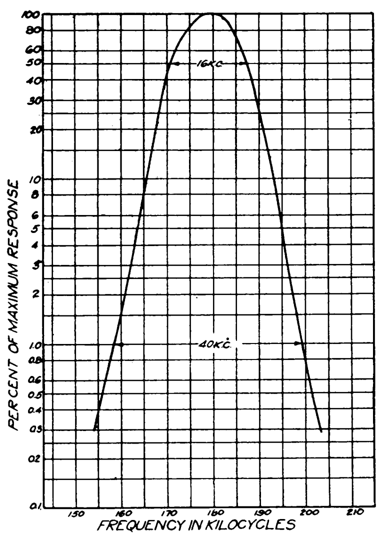

Fig. 8

the two brackets for supporting the transformer windings. Fig. 9 illustrates the manner in which these condensers, the transformer windings, and the terminals are mounted. A transformer completely assembled ready to mount on the chassis is shown in Fig. 10.

AUDIO-FREQUENCY SYSTEM

The audio-frequency detector in radio receiving sets is responsible for some distortion and contributes to such disturbances as microphonic howl and a.c. hum.

These objectionable features are considerably reduced, and other performance advantages are gained by employing a plate circuit detector and by using but one audio stage.

The relative merits of the conventional audio system consisting of a grid circuit detector and two audio stages as compared with a combined radio and audio system employing a radio-

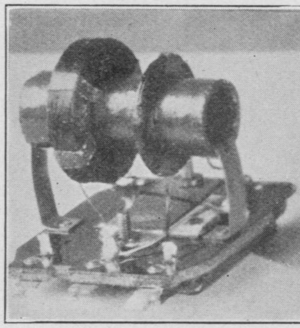

Fig. 9

frequency stage, plate circuit detector, and one audio stage are as follows:

Changing from a grid circuit to a plate circuit detector in a given receiver results in a sacrifice in sensitivity. This reduction in sensitivity can be overcome by increasing the radio-frequency

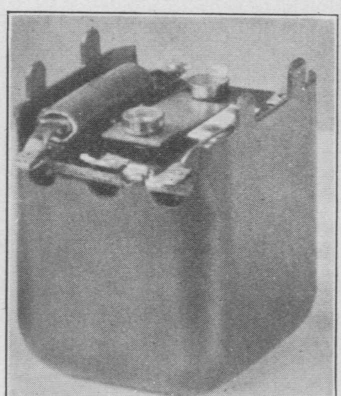

Fig. 10

amplification and reducing the audio-frequency amplification. In general, it can be said that substituting a radio-frequency stage of equal amplification for an audio stage will result in no loss of sensitivity from substituting a negatively biased detector for a grid leak and condenser detector.

With improved audio response, particularly at low frequencies, when two audio stages are used, it has become increasingly difficult to avoid a.c. hum from the power supply, and audio howls due to the microphonic action of tubes. The blasting and breaking up of the sound output when tuning through a local station is ordinarily due to overloading the output tube. This disturbance can be reduced if the circuits are so designed as to allow the detector and output tube to overload at the same time.

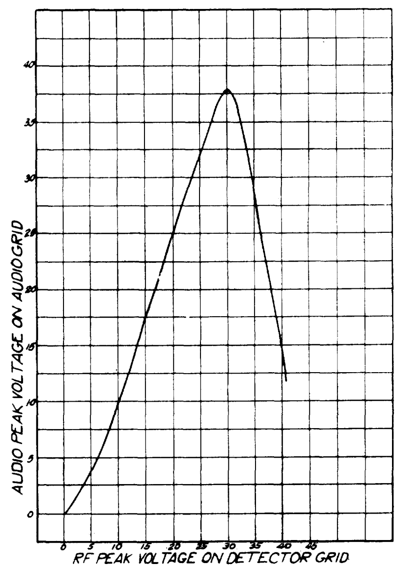

Fig. 11

The time lag distortion associated with detectors employing grid leak and condenser combinations is not present when plate circuit detection is used.

The curve in Fig. 11 shows the relation between the peak voltage on the grid of a UY-227 tube functioning as a negatively biased detector and the peak audio voltage on the grid of the audio amplifier tube. The plate potential on the UY-227 tube is 180 volts and the bias 25 volts. The carrier is modulated 15 per cent at 100 cycles. The reduction in output for an input in excess of 30 volts is due to the grid current load on the tuned circuit, through which the voltage is applied to the detector grid.

Automatic Volume Control

A receiving set equipped with a practical automatic volume control has several distinct advantages over the set which lacks this equipment.

One of the chief advantages is the ability to change the tuning of the receiver without making any change in the volume control setting. Once the volume control has been set for the desired sound output, either distant or local stations may be tuned in without any further volume control adjustment. If the distant station provides sufficient field strength (depending

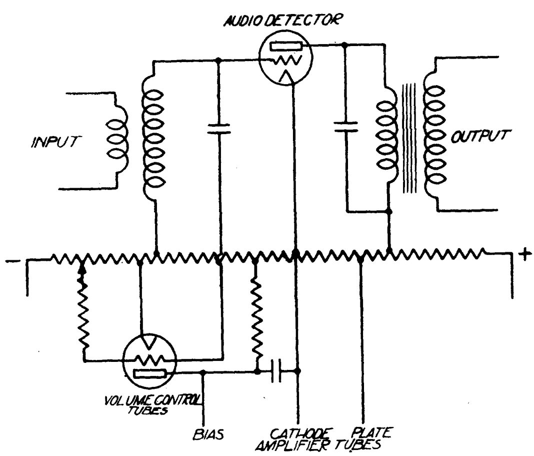

Fig. 12

on the maximum sensitivity of the receiver) it will produce practically the same sound output as the local station. It is assumed that the per cent modulation used by both stations is nearly the same.

The ability of an automatic volume control to limit the sound output to any desired value is of particular importance in light of the present trend towards the use of output tubes capable of handling considerable power.

While automatic volume controls have sometimes been called fading eliminators, this term is, of course, erroneous. An effective automatic volume control, however, does automatically adjust the sensitivity of the receiver while the field strength from a station is varying so as to maintain a constant output

There are numerous occasions when a powerful distant station has sufficient field strength at any time during an evening to give a satisfactory loudspeaker signal, but the field strength varies through such a wide range and so frequently that the program cannot be received satisfactorily without continuous adjustment of the volume control. Under such conditions an automatic volume control will function satisfactorily. The only indication that the user will have that the signal is fading will be an increase in the ground noise when the signal drops to such

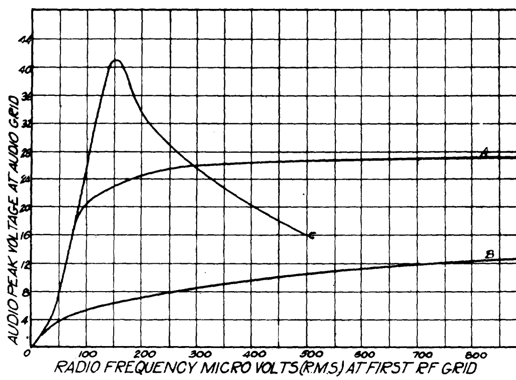

Fig. 13

a value that nearly the maximum sensitivity of the receiver is required to produce the desired sound output.

There are some types of fading that are accompanied by a distortion of the audio modulation, and in such cases an automatic volume control will be of little value as far as compensation for this type of fading is concerned.

The chief objections to past automatic volume control systems have been the number of adjustments required and the use of separate voltage supplies for certain parts of the circuit. To obtain sufficient control some systems also require additional amplification either for the a.c. voltage on the detector grid or for the bias voltage before it is impressed on the amplifier grids. This latter objection is overcome by the use of but one stage of audio amplification and the corresponding increase in the grid swing on the detector tube. Fig. 12 shows a schematic diagram for an arrangement which overcomes the other objections. The grid of the volume control tube is connected in parallel through a coupling condenser to the grid of the second detector. The voltage drop across a resistor in the plate circuit of this tube is used as additional negative bias on the amplifier tubes and thus reduces the sensitivity of the receiver. The values of this plate circuit resistor and its shunting capacity are so chosen as to give the combination a time constant sufficiently low to prevent the smoothing out of the lower modulation frequencies and still high enough to prevent its action from being sluggish.

The bias on the volume control tube is normally adjusted to the point where, when no signal is being received, the tube

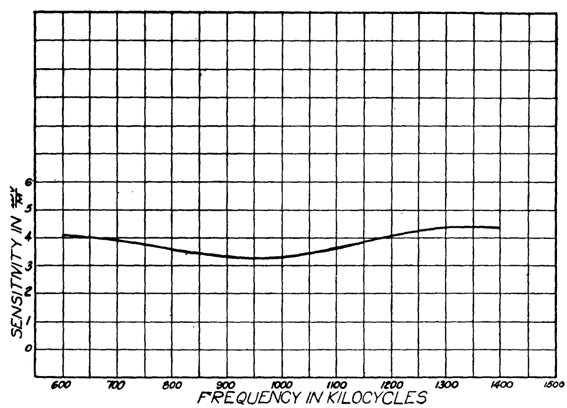

Fig. 14

draws no current. Then when the grid swing on the second detector exceeds a certain value, the effective bias on the control tube is reduced and its plate current increased. This increase in plate current causes a corresponding increase in the bias voltage applied to the radio-frequency and intermediate frequency amplifier tubes with a resultant reduction in the sensitivity of the receiver, thus tending to maintain a uniform grid swing on the second detector. By means of a manual control the negative bias on the volume control tube can be increased permitting a larger grid swing on the detector tube before the automatic volume control tube takes effect. In this manner any desired audio output can be obtained. The variation of the bias on the volume control tube as the manual adjustment for the output level also compensates for the manufacturing variations in cutoff of the tubes as automatic volume control tubes. Curves *A* and *B* in Fig. 13 show the effectiveness of the automatic volume control for two output levels. Curve *C* shows the variation in output without the automatic volume control.

The use of an automatic volume control in a radio receiver presents some problems which are not encountered when this equipment is not used. Due to the automatic volume control maintaining constant audio output, it is difficult to tune the receiver accurately unless some resonance indicating device is provided. A meter in the plate circuit of either the control tube or the tubes controlled provides a satisfactory resonance indicator.

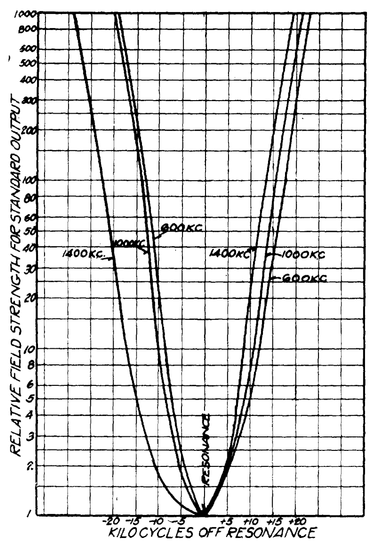

Fig. 15

In localities where there is considerable interference due to power line leakage, etc., the noise encountered when tuning between stations with a set equipped with automatic volume control is objectionable unless a sensitivity control is provided. This is due to the fact that when no signal is being received the receiver is automatically adjusted for maximum sensitivity, and the time constant of the automatic volume control circuit is such that it does not limit the sharp impulses of such interference. The sensitivity control may be a voltage divider which varies the normal bias on the amplifier tubes, or in receivers where an untuned input circuit is employed a voltage divider may be used to vary the signal potential on the grid of the input tube.

By means of the sensitivity control, the maximum sensitivity of the receiver can be reduced to such a value that the noise encountered in tuning between stations is not objectionable. This sensitivity control will in no way destroy the effectiveness of the automatic volume control.

Overall Performance

The major electrical elements of a modern superheterodyne receiver have been briefly discussed. The performance char-

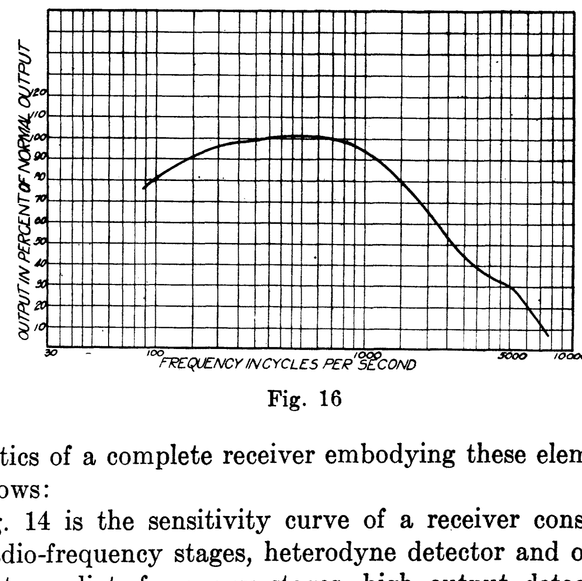

Fig. 16

acteristics of a complete receiver embodying these elements are as follows:

Fig. 14 is the sensitivity curve of a receiver consisting of two radio-frequency stages, heterodyne detector and oscillator, two intermediate-frequency stages, high output detector, and single audio stage. The receiver employs UY-227 tubes throughout except for the power output tube.

The three curves in Fig. 15 show the selectivity of the receiver at three frequencies in the broadcast range. The fidelity characteristic of the complete receiver is shown in Fig. 16.

The curves show the high uniform degree of selectivity obtained by the use of the eight tuned circuits while still retaining unusual fidelity characteristics.