

THE SUPERHETERODYNE RECEIVER

By
ALFRED T. WITTS
A.M.I.E.E.

THIS book describes the operation of Superheterodyne Receivers in the clearest possible manner. It makes every detail of the subject understandable and provides the essential working knowledge required by every keen amateur constructor, student of radio, and service engineer

P I T M A N

THE SUPERHETERODYNE RECEIVER

ITS DEVELOPMENT, THEORY AND
MODERN PRACTICE

BY
ALFRED T. WITTS, A.M.I.E.E.



SECOND EDITION

LONDON
SIR ISAAC PITMAN & SONS, LTD.

1936

SIR ISAAC PITMAN & SONS, LTD.
PITMAN HOUSE, PARKER STREET, KINGSWAY, LONDON, W.C.2
THE PITMAN PRESS, BATH
PITMAN HOUSE, LITTLE COLLINS STREET, MELBOURNE
ASSOCIATED COMPANIES
PITMAN PUBLISHING CORPORATION
2 WEST 45TH STREET, NEW YORK
SIR ISAAC PITMAN & SONS (CANADA), LTD.
(INCORPORATING THE COMMERCIAL TEXT BOOK COMPANY)
PITMAN HOUSE, 381-383 CHURCH STREET, TORONTO

PREFACE

TO SECOND EDITION

ALTHOUGH the first edition was published only a matter of months before the present date, the writer has found it necessary to make several alterations in the contents of the book in order to justify its sub-title "modern practice." Four of the commercial receivers described in the seventh chapter of the previous edition have been replaced by comments on up-to-date models, and in the chapter on superheterodyne problems, notes have been added on the more recent developments such as variable selectivity, all-wave receivers, car radio, automatic tuning correction, etc. Various other items have been added, such as a description of frequency changing without rectification, and several sections have been amplified. Opportunity has also been taken to clarify some of the statements that had not been too clearly expressed.

In response to several requests, a chapter on practical receiver testing has been added.

A. T. W.

September, 1935.

PREFACE

TEXTBOOKS on wireless subjects have, up to the present, given but scanty information on the working of the Superheterodyne receiver. This is not to be wondered at, for until three years or so ago the Superheterodyne was regarded in this country more as an academic type of receiver than as a practical means of obtaining selective radio reception of high fidelity. Recent developments have completely changed the position of this receiver, and it is now largely replacing other types.

There must be many amateurs, students, and radio servicemen who have desired more complete and up-to-date information on the working of the Superheterodyne Receiver than that available in the wireless books so far published. It is hoped that this book will meet that requirement.

No attempt has been made to give practical hints in the design or operation of the receiver, for these would be out of place in a book which aims at presenting a theoretical survey.

I wish to express my appreciation of the assistance I have received from Mr. W. H. Nottage, B.Sc., M.I.E.E., F.Inst.P., who has corrected the manuscript and proofs, and offered many valuable suggestions.

I also acknowledge, with thanks, the co-operation of the Companies who supplied me with information regarding the technical points of their receivers described in this book.

ALFRED T. WITTS.

LONDON,
1934.

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THE SUPERHETERODYNE RECEIVER

CHAPTER I

THE EVOLUTION OF THE SUPERHETERODYNE RECEIVER

ONE of the major problems in the early days of wireless communication was the reception of weak signals. Owing to the insensitivity of the coherer and magnetic detectors then in use, the range of the wireless transmitting stations was seriously limited and the attention of the engineer was consequently turned towards the development of a more efficient receiver.

It was, no doubt, during the consideration of this problem that it occurred to R. A. Fessenden (an American engineer, who later had a great deal to do with the development of wireless signalling in the United States) that an improvement might be achieved if the transmitting station were made to send out signals in such a way that their combined effects at the receiver reproduced the desired signal. One way to do this would be to transmit two frequencies differing by a low frequency, so that if they were combined and detected at the receiver audible beats would be produced which could be used for signalling purposes.

Fessenden's patent covering this idea, filed on 28th September, 1901, was the first of a number of important steps leading away from other types of receiver towards the superheterodyne. It constitutes the first recorded proposal for the utilization of beat frequency phenomena in wireless communication.

The receiver is shown in Fig. 1. Aerials A_1 and A_2 are each tuned to a frequency sent out by the transmitting station, and are

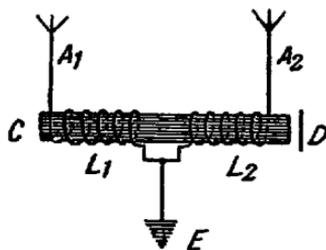


FIG. 1. CIRCUIT ARRANGEMENT OF THE FIRST BEAT RECEIVER

connected respectively to coils L_1 and L_2 , and thence to earth. Coils L_1 and L_2 are wound on a fine iron wire core C , and the currents flowing through them combine their effects to actuate the detecting telephone D according to their phase. This type of receiver was designed for telegraph signalling, which was effected at the transmitting station either by interrupting one transmitted wave while the other was being sent out continuously, or else by interrupting both waves simultaneously.

Having found a method of forming beats, Fessenden's next idea was to produce them more easily and economically. He did this by using a single wave transmission and causing a locally generated high frequency current at the receiver to interact with it to form the audible beats. With this method the resultant beat note was within the control of the receiving operator—an important point

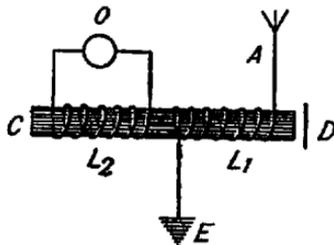


FIG. 2. THIS SHOWS THE
CIRCUIT OF THE FIRST
HETERODYNE RECEIVER

during reception in bad atmospheric conditions. The local oscillation generator was called a *heterodyne*, this being a derivative of the Greek words *Heteros* (other or external) and *Dynamis* (force).

Fessenden's heterodyne method was very simple, and is shown diagrammatically in Fig. 2. On to a common core C were wound two coils, L_1 and L_2 . Coil L_1 was connected between aerial and earth, while L_2 was joined to the local oscillation generator or heterodyne O , the frequency of which was variable. Incoming oscillations passing through L_1 would be superimposed on the oscillations supplied to L_2 , and the resultant "beat" or difference frequency was brought within the audible range by suitable adjustment of the generator O and it then actuated the detecting telephone D .

The heterodyne system of reception was not developed for several years. In the state its inventor had left it, the efficiency was very low owing to the poor sensitivity of the non-polarized type of telephone that had to be used with it due to the necessity for the reproducer to give a result that bore a relation to the integrated applied energy. The reproducer used in the receiver adopted by an American signalling company was a delicate static telephone placed directly in the aerial circuit. A range of 3000 miles was recorded with this type of receiver.

In 1910, during some tests between two American cruisers, the wireless operator noticed that the received signal strength increased greatly when the ship's transmitter was started up. The difference between the received and transmitted

EVOLUTION OF SUPERHETERODYNE RECEIVER 3

frequencies was about 20,000 cycles per second, which is above audibility.

Investigation into this matter led to the design of a much more sensitive heterodyne receiver, in which the static telephone was replaced by a normal rectifier and telephones. The receiver circuit at this stage was as shown in Fig. 3. Inductance coil L_1 is the loading coil, L_2 is for coupling the aerial circuit via L_5 to the

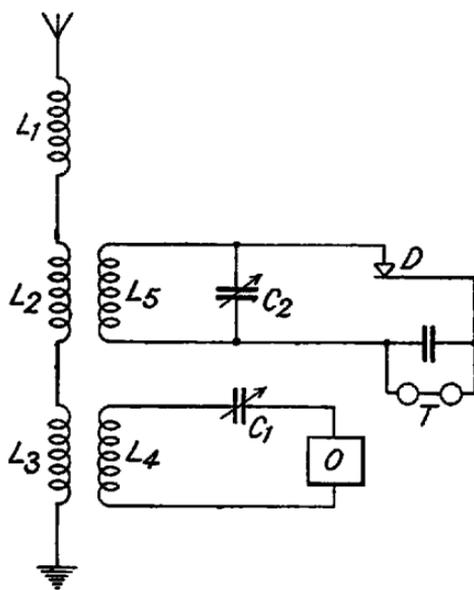


FIG. 3. AN EARLY CIRCUIT IN WHICH A RECTIFIER IS EMPLOYED IN A HETERODYNE RECEIVER

rectifier circuit, and L_3 is for coupling the aerial to the heterodyne O via L_4 . The heterodyne frequency is adjusted by condenser C_1 , to the value required, so that the combined incoming and locally generated high frequency currents are generated in the aerial circuit. The beats are picked up by coil L_5 , which with C_2 forms a resonant circuit tuned to the incoming signal frequency, and are rectified by D . Coils L_4 and L_5 are not coupled.

In 1913 the heterodyne receiver showed up well in the American naval tests between the Arlington, Virginia, land station and the warship *Salem*. Reception was maintained up to 6400 miles, and the heterodyne method not only proved to be more sensitive than other methods (ticker and electrolytic detector), but was also much superior during reception under bad atmospheric

conditions. This was due to the fact that by varying the frequency of the heterodyne, the resultant beat note could be altered in pitch to make it easily distinguishable from the atmospheric disturbances, whereas the other types of receivers gave an audible indication that differed but slightly, if at all, from that produced by the atmospherics. The local oscillation generator used in these tests was a high frequency alternator.

In 1913 the thermionic valve, which previously had only been used for rectification and amplification of high frequency currents, was made to generate oscillations. The inventors of the valve oscillation generator were G. Arco and A. Meissner, of the German

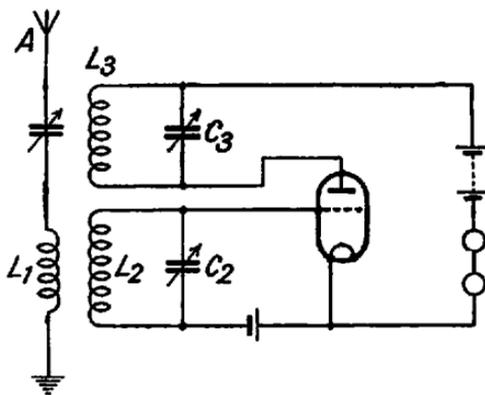


FIG. 4. ROUND'S AUTODYNE CIRCUIT

Telefunken Company. The method used by Arco and Meissner to cause the valve to generate oscillations, was to feed back energy from the output circuit into the input circuit. This idea applied to a thermionic valve was novel, and resulted in a new phenomenon so far as the working of the valve was concerned, although the broad principle of feeding back electrical energy was well known in the engineering world, having been used in 1911 by S. G. Brown in his amplifying microphone. Curiously enough, Irving Langmuir, working quite independently in America, discovered a similar method of producing valve generated high frequency oscillations shortly after Arco and Meissner had filed their patent application in Germany.

The advent of the valve generator stimulated interest in the heterodyne method of reception. A valve oscillator was not only less expensive than a high frequency alternator or an arc generator, but it was also much more compact and easily handled.

Towards the end of 1913 Captain H. J. Round invented the

autodyne receiver circuit. In this invention a valve was used to generate the heterodyne oscillations, superimpose them on the incoming high frequency currents, and rectify the resultant beats. In effect it created the one-valve heterodyne receiver.

One of the circuits used by Round in his autodyne receiver is shown in Fig. 4. The incoming currents pass through coil L_1 to earth, and induce a current in the valve input circuit $L_2 C_2$ which is tuned to the incoming frequency. The output circuit $L_3 C_3$ is tuned to a frequency slightly different from the signal frequency (either above or below), and L_3 is coupled to L_2 to supply the feed-back necessary for the generation of oscillations. The self-generated current combines with the incoming oscillations in the circuit $L_2 C_2$ to produce the beats which are then rectified by the valve and delivered to the reproducer.

Round's invention was not confined to the rectifying valve, but could be used, for instance, in a high frequency stage. In this case, the valve performed the function of "mixer," i.e. it amplified the signal currents and then combined them with the self-produced oscillations, delivering the beats to a separate rectifier.

WAR-TIME DEVELOPMENTS

When the World War began wireless research on both sides of the fighting front was very intense in an effort to produce receivers which would give high amplification.

H. J. Round, M. Latour, and, later, E. H. Armstrong, on the Allied front, and W. Schottky for the Germans, each devoted considerable thought and investigation to the common problem of the selective reception of very weak signals on, at that period, the very high frequency of 500 to 3000 kilocycles per second (corresponding to a wavelength of 600 to 100 metres).

The limitations to the construction of a high frequency amplifier for those frequencies were: instability due to valve inter-electrode capacity, which allowed undesirable feed-back of energy from the output circuit to the input circuit; and the disastrous result of the capacitative effects of the receiver components which caused the high frequency energy to be by-passed from the coupling elements. At frequencies lower than 500 kilocycles little difficulty was encountered due to these troubles. This was because, since the reactance of capacity varies inversely as the frequency, the lower the frequency the higher will be the reactance in shunt to the receiver components, and correspondingly less energy will be by-passed.

On the low frequency current side of the receiver, the limitations of the amplifier were equally stringent, owing to the inherent noise in the valve itself due to its method of functioning. Furthermore, the detectors all had square law characteristics. This meant that

for very weak signals—the type with which research was mainly confined—practically no response took place at all.

Round in England and Latour in France were able to construct high frequency amplifiers which were quite successful. Round developed the low capacity valve (known as Type V24) in 1916 and used transformers made of high resistance wire to suppress the tendency to self-oscillation. Latour used fine wire iron cores in his high frequency transformers which had the ultimate effect of increasing the resistance of the circuit. These receivers were only successful up to a point; a high-gain amplifier was still required and sought after.

We must here leave for the moment the searches for a sensitive and selective receiver in order to examine the results of experiments by a French electrical engineer, Lucien Levy, who desired to produce a receiver that would be immune from the effects of atmospheric or interference by unwanted stations. Levy evolved in 1917 a system of transmission and reception which he claimed would completely eliminate "parasites and ordinary interference" from the receiving station. His method of reception used the superheterodyne principle, and the patent covering his proposals, filed on 4th August, 1917, constitutes the first subject-matter on this type of receiver.

LEVY'S RECEIVER

It should be emphasized here that Levy's problem was not entirely the same as Armstrong's and Schottky's, to be described later. Levy was solely concerned with the reduction of interference due to the reception of undesired transmissions and to atmospheric. The idea of Levy's invention was to bring the desired signal currents to such a frequency that they could be easily separated from the interfering stations and atmospheric before being amplified. This was done by means of a heterodyne, the frequency of which was so adjusted as to cause ultra-acoustical beats when superimposed on the incoming oscillations. These beats, after rectification, were passed through a high-pass filter and, if need be, an amplifier, before being combined with currents from a second heterodyne to be brought below the audible limit and again rectified for reproduction. His system was primarily designed for reception of telegraphic signals, and that is why the second heterodyne is essential.

Levy claimed that the ultra-acoustical beats would be so far separated in frequency from atmospheric disturbances and many interfering stations, that they could be easily selected clear from these. As he was doubtless troubled with the difficulty encountered by Round and Latour—instability—Levy could not use a multi-valve amplifier tuned to the frequency of the incoming carrier

wave. A further advantage of the first heterodyne was, therefore, that ultra-acoustical beats were produced which could be tuned without such a serious risk of interaction and instability. This afforded additional selective means.

Levy's receiver circuit is shown in Fig. 5. L_1 is the aerial coil, coupled to L_2 in the valve input circuit tuned by condenser C_2 to the incoming carrier frequency. Condenser C_1 and resistance R are for normal grid detection. The heterodyne oscillations are supplied to coil H_1 coupled to L_2 . In the output coil L_3 will flow currents of the intermediate frequency, and these are transferred over the high pass filter to the input of the succeeding valve.

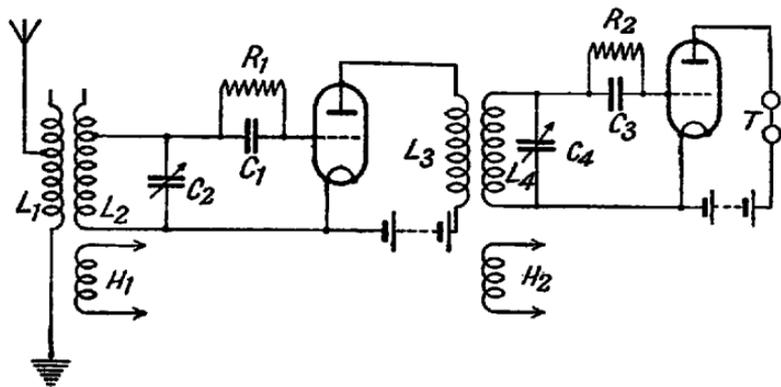


FIG. 5. THE EARLIEST RECORDED CIRCUIT USING THE SUPERHETERODYNE PRINCIPLE, BY L. LEVY

The important fact from the superheterodyne standpoint is that Levy specifically intended an amplifier, tuned or otherwise to the intermediate frequency, to be inserted between the two valves shown in Fig. 5, if such an amplifier was required.

Circuit $L_4 C_4$ is tuned to the intermediate frequency. C_3 and R_2 are for grid rectification, H_2 contains the second heterodyne currents, and T is the acoustical reproducer.

The diagram of Levy's receiver as shown in Fig. 5 is clearly a superheterodyne circuit, and it represents the first recorded contribution to the superheterodyne art. Levy's invention was of fundamental importance.

ARMSTRONG'S RESEARCH WORK

Returning now to the problem of building powerful amplifiers for war purposes, we find that when the American forces came to Europe, the new technique of receiver design developed by Round

and Latour was quite unknown to them. The American wireless receivers and valves were quite inadequate for the short wave work they were required to take part in.

While investigating the amplifier difficulties it occurred to Major E. H. Armstrong, of the American Expeditionary Force, that the problem would be solved if the incoming oscillations were combined with a locally produced high frequency current to produce a beat frequency in the manner well known at that time, but instead of the beat frequency being audible it would be ultra-audible, and of such a frequency that the valves and amplifiers then in use could amplify the signals far more effectively than they did the high frequency of the original signal currents. These inaudible beats after rectification would still contain the modulation forming the signal, and after suitable amplification could be rectified in the usual way and the resulting low frequency currents again amplified.

This is the principle of the superheterodyne, and to E. H. Armstrong is to be given the credit of being the first one to develop a system of reception utilizing these principles. Armstrong's patent application, however, was over six months behind Schottky's in Germany.

Experiments were carried out along the lines of Armstrong's supersonic beat frequency amplifier proposals by the Division of Research and Inspection of Signals Corps of the American Expeditionary Force. An eight-valve superheterodyne was actually constructed, consisting of first detector, heterodyne, three stages of intermediate frequency amplification, second detector and two stages of low frequency amplification. The signing of the Armistice, however, temporarily suspended the experiments. Armstrong applied for a patent covering his ideas on the 30th December, 1918.

The basic idea in Armstrong's invention can be seen from Fig. 6. Incoming oscillations are supplied to coil L_1 which is coupled to coil L_2 forming, with a condenser C_1 , a circuit tuned to the incoming signal frequency. Locally generated high frequency currents are fed to coil H , and by means of the coupling between coils H and L_2 are superimposed on the signal currents to form an intermediate supersonic frequency which is rectified by the detector D . The intermediate frequency is transferred to amplifier A via the coupling coils T_1 . After amplification, which is easily performed at this much lower frequency, the intermediate frequency is applied to the second rectifier D_2 and reproducer R . If the signals are undamped (from a continuous wave transmitter), then a second heterodyne H_2 will have to be employed in order to make them audible.

The use of multiple frequency conversion is distinctly claimed

in Armstrong's patent. This method is of particular importance in the construction of very powerful amplifiers. After the first frequency conversion to a beat frequency of, say, 1000 kc/s, the currents can be amplified and then again converted, this time to a frequency of, say, 100 kc/s, which is amplified and detected. In this case there would be two supersonic frequency amplifiers and three detectors. Still further frequency conversion, amplification, and detection could be carried out so long as the upper limit of audibility was not too nearly approached.

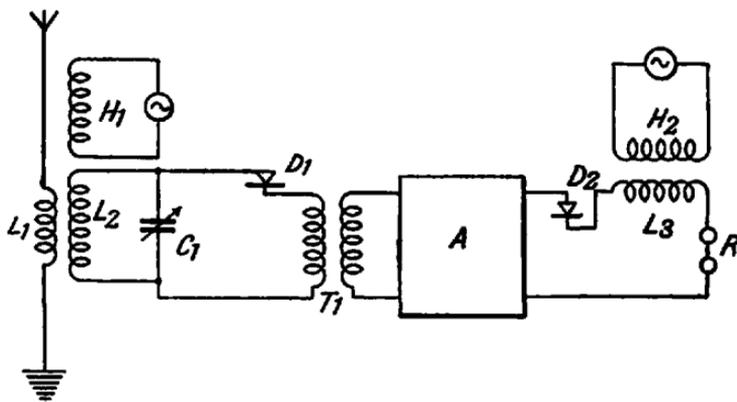


FIG. 6. ONE OF THE CIRCUIT ARRANGEMENTS COVERED BY ARMSTRONG'S SUPERHETERODYNE PATENT

This method of multiple frequency conversion is used to-day on important commercial trans-oceanic receivers, as will be described later.

SCHOTTKY'S SUPERHETERODYNE PATENT

Having surveyed the preliminary development of the superheterodyne on the Allied side of the fighting front, let us now take a glance at the events on the other side.

There, the problems in connection with the reception of weak signals were similar to those encountered by the Allied investigators, and experiments were undertaken by the Germans to find a means of rejecting the unwanted signals from the desired ones and for constructing powerful receivers.

It was during consideration of these difficulties, early in 1918, that it occurred to W. Schottky, part-manager of the Siemens Laboratory (the Schwachstromkabel Laboratorium) that, to use his own words, "the incoming oscillations could be linearly converted like ordinary heterodyne reception into a lower frequency

wave, easily amplified, by causing the first receiver valve to oscillate at a frequency giving inaudible beats when receiving the incoming high frequency." Schottky considered that, if a linear conversion of the wave was to be effected, the amplitude of the heterodyne should be such that it controlled the "mixer" valve over about one-half of its characteristic.

Notes outlining the ideas expressed above were made in the *Journal of the Schwachstromkabel Laboratorium* for the period 25th February to 16th March, 1918, and a patent application covering the ideas was filed on the 18th June, 1918. Schottky apparently could not investigate the possibilities of his conception, and the matter was left in the undeveloped state.

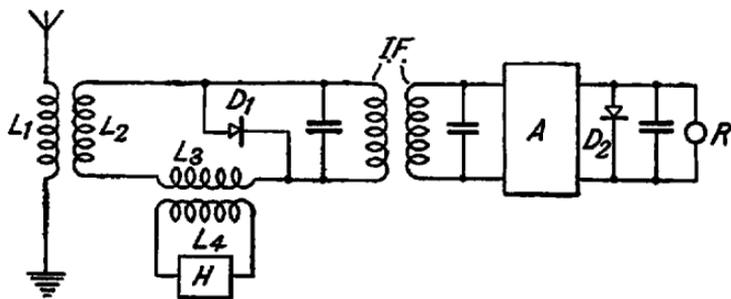


FIG. 7. SCHOTTKY'S PROPOSED CIRCUIT FOR SUPERHETERODYNE RECEPTION

The drawing in the Siemens' superheterodyne patent is shown in Fig. 7, and it will be observed that the circuit arrangement is almost identical to Armstrong's. Signal currents in coil L_1 induce oscillations in coil L_2 . Heterodyne H supplies high frequency currents to the receiving circuit via the coupling coils L_4 and L_3 , and the superimposed currents are rectified by D_1 . Coupled circuits are tuned to the supersonic beat frequency. The rectified currents pass through amplifier A , and are rectified a second time by D_2 , which thus supplies audible frequency currents to the reproducer R .

In the Siemens' patent the point stressed is that unless the intermediate frequency currents are amplified, the second detector is supplied with oscillations of an amplitude no greater than that of the aerial current, and consequently the square law detector would still operate under the difficulty it was desired to overcome. As in Armstrong's patent, it is mentioned that if the intermediate frequency amplifier is tuned to the intermediate frequency, greater selectivity will result.

From the foregoing notes it can be seen that the outstanding names associated with the early development of the superheterodyne are—

1. R. A. Fessenden, who invented the heterodyne receiver in America in September, 1901.
2. L. Levy, who used the superheterodyne principle in a receiver designed for the elimination of atmospherics, in France, April, 1917.
3. W. Schottky, who was the first to describe a superheterodyne receiver intended to be a powerful and selective amplifier, in Germany, in June, 1918.
4. E. H. Armstrong, who not only conceived the idea of the superheterodyne, but was the first to investigate the practical capabilities of this type of receiver late in 1918.

CHAPTER II

POST-WAR DEVELOPMENTS

FOR some time after the end of the War there was a lull in the development of the superheterodyne receiver. The need for a high-gain amplifier still existed, but was not so urgent for the commercial services owing to the fact that very high power was employed at the transmitting stations. At that period, too, there was not very severe interference between stations, as the wireless telegraph services were comparatively few in number. The receiving apparatus available was sufficiently good for the demands made upon it.

Little was heard of the superheterodyne receiver until the winter of 1921. Then tests were carried out between radio amateurs on both sides of the Atlantic, with E. H. Armstrong prominent among the Americans. The object of the tests was to see if the amateurs could transmit across the Atlantic.

This was achieved in December, 1921, when a number of British amateurs, including Paul F. Godley, the official representative of the Relay League (United States), at Ardrossan, Scotland, received several American amateur stations. The receiver Godley used was of the superheterodyne type and consisted of first detector, separate oscillator, five resistance-capacity coupled valves as the intermediate frequency amplifier, second detector and one stage of low frequency amplification. The intermediate frequency was 100 kc/s. Godley claims to have been using the superheterodyne receiver for two years prior to the date of the transatlantic tests. In this event he must have been among the very earliest experimenters in superheterodyne reception.

EARLY UNPOPULARITY OF THE SUPERHETERODYNE

The great opportunity for the superheterodyne receiver arrived with the advent of broadcasting. Cost, however, was the limiting factor, for not only did the superheterodyne require more valves and components to produce the same results as a straight set, but the accessories were far more expensive. In the initial stages of broadcasting, for example, most receiving valves required three-quarters to one ampere of current for the filament, which had to be supplied by an accumulator battery. The cost of filament supply alone for an eight-valve receiver was thus prohibitive in most cases.

Another drawback that made the superheterodyne receiver a

luxury was the separate oscillator which performed no useful part in the amplification of the signal currents. It was a "passenger" in the listener's opinion. Efforts to use one valve as combined first detector and oscillator were not very successful for three reasons. One reason was that the loss of amplification caused by detuning (as described in the notes on Round's autodyne patent) compensated for the gain of a valve, so that from the amplification aspect the listener was no better off. Although the autodyne receiver was very successful for ordinary continuous-wave signals, where detuning to the extent of only one thousand or even a few hundred cycles per second gave the desired results, it could not reasonably be expected to stand detuning by 50,000 or 100,000 cycles per second, as was required for superheterodyne reception, without serious loss of signal strength, especially at the lower frequency end of the broadcast band.

The second disadvantage of the autodyne method of frequency transformation was the difficulty encountered in getting a valve to maintain oscillations in one tuned circuit at a frequency differing but slightly from the oscillations in a second tuned circuit. This difference in frequency was only about 10 per cent in many cases, and any alteration in the tuning of one circuit would, owing to the input and output circuit coupling, cause reaction in the other. The entire arrangement was, indeed, so critical that it tended to go out of adjustment with the change in tuning.

A third objectionable feature of the autodyne frequency converter for broadcast reception was the interference it set up among nearby receivers by its radiation. It will be observed from the diagram of the autodyne (Fig. 4) that the output circuit is coupled to the aerial circuit. This is a necessary arrangement if the first valve is a combined first detector and local oscillator. Consequently the locally generated frequency will be strongly radiated from the receiving aerial.

It will thus be seen that when broadcasting began the superheterodyne receiver had not reached the stage in which it could make a ready appeal to the layman. Furthermore, a very successful high frequency amplifier had been developed with which the superheterodyne had to compete even when the above difficulties had been overcome. This was the Neutrodyne receiver, in which the effect of the inter-electrode capacity of the valves was neutralized, enabling comparatively high-gain amplifiers to be constructed. A good Neutrodyne amplifier, nevertheless, demanded great attention to screening and design, and the receivers were rather costly.

HOUCK'S HARMONIC HETERODYNE

Efforts to reduce the minimum number of valves necessary for operating the superheterodyne receiver were continued by

Armstrong and his associates. A practical solution to the combined detector-oscillator problem was developed by Harry W. Houck, who invented the harmonic heterodyne early in 1923. Houck's invention, which was a modification of Round's autodyne, overcame to some extent the three objections to the use of the latter referred to above.

In the harmonic heterodyne receiver the aerial was coupled to a circuit tuned to the frequency of the incoming carrier waves as usual. A separate tuned circuit connected to the grid, which

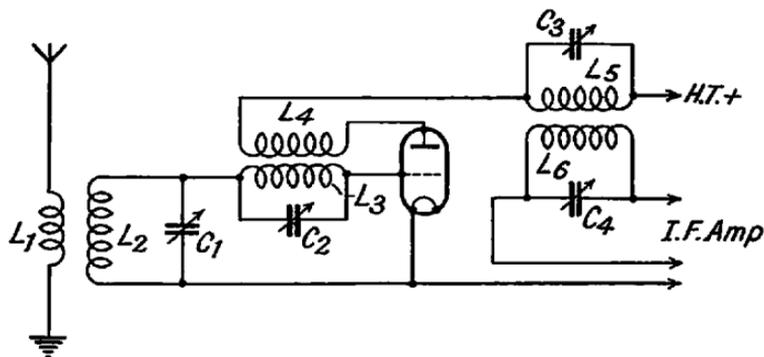


FIG. 8. HOUCK'S HARMONIC HETERODYNE CIRCUIT

received the feed-back from the anode circuit, was tuned to a frequency that was a sub-multiple of the desired heterodyne. The second harmonic (double the frequency of the fundamental oscillations) is thus superimposed on the incoming high frequency currents to produce the desired super-audible beats, which are rectified by the valve and passed on to the output circuit which has a resonant circuit for the intermediate frequency.

Houck's circuit is shown in Fig. 8. The signal currents pass through L_1 coupled to L_2 forming a circuit with C_1 , tuned to the incoming signal frequency. Valve oscillations are maintained by the feed-back across L_4 L_3 at the resonant frequency of circuit L_3 C_2 . This frequency is equal to half the frequency of the incoming signals plus or minus half the required intermediate frequency. Owing to the non-linear operation of the valve a number of harmonics will be generated. The second harmonic is combined with the incoming carrier wave, and the combined wave is rectified by the valve to produce in the output circuit the desired intermediate frequency. Circuit L_5 C_3 is tuned to this frequency, which is thus passed over L_6 to the intermediate frequency in the usual way.

It can be seen that as the oscillation circuit $L3 C2$ is tuned to a frequency so widely separated from the signal input circuit $L2 C1$, there is but slight tendency for tuning variation in one circuit to react on the other. The arrangement is, therefore, very stable. For the same reason radiation is reduced to a considerable extent. Loss of signal strength due to the use of a single tuned oscillatory circuit for the autodyne receiver does not apply here as the incoming signal is tuned by $L2 C1$.

TROPODYNE CIRCUIT

Another circuit which was developed to enable one valve to be used as oscillator and first detector was known as the "Tropodyne"

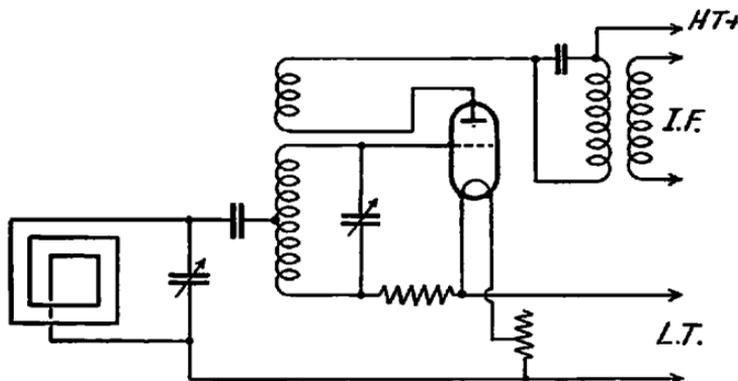


FIG. 9. THE TROPODYNE CIRCUIT

and is shown in Fig. 9. In this circuit a frame aerial was employed, tuned to the incoming high frequency by a variable condenser connected across it. The aerial circuit was coupled to the valve input circuit by a condenser, which at the same time acted as grid condenser for rectification purposes, the grid leak being in the grid return. This grid coupling condenser is connected to the electrical centre of the valve input inductance coil. The valve grid circuit is tuned to the heterodyne frequency, and oscillations are maintained by feed-back from a coil in the output circuit in the usual manner.

Reaction between the aerial and valve input circuits is obviated by coupling the aerial circuit to the nodal point of the input coil. Consequently the resonant frequency of either circuit can be altered at will without the arrangement being thrown out of adjustment. As with Houck's harmonic heterodyne circuit, the serious loss of signal strength through detuning, which the autodyne receiver

usually involves for superheterodyne work, does not occur in the Tropodyne, owing to the incoming signals being tuned-in by the aerial circuit.

ARMSTRONG'S REFLEX AMPLIFIER

Armstrong went one step further in his search for valve economy, and devised an arrangement whereby the first valve, in addition to amplifying the signal high frequency currents, was made to function as amplifier of the intermediate frequency as well. The reason for adding a high frequency amplifier to the superheterodyne receiver was that it made the receiver far less susceptible to second channel interference, and to interference due to harmonics of the oscillator being superimposed on unwanted signals, and thus setting up currents of the intermediate frequency. These points will be explained later.

Armstrong's combined H.F. and I.F. amplifier circuit is shown in Fig. 10. The frame aerial is tuned by condenser *C1* to the incoming high frequency signal which is applied to the grid of valve *V1*. Amplified high frequency currents in the plate circuit of valve *V1* are induced via the untuned high frequency transformer *T1* into the grid circuit of valve *V2*, which is acting as a Houck harmonic heterodyne valve as previously described. The second harmonic of the oscillations of valve *V2* due to the reaction coupling *L3 L4* (circuit *L3 C3* being tuned to the fundamental) are combined in its grid circuit to form, after rectification, the intermediate frequency currents. In the plate circuit of *V2*, coil *L2*, which is tuned by condenser *C2* to the I.F., is coupled to coil *L1* in the grid circuit of the high frequency amplifier valve *V1* in parallel to the frame aerial. The intermediate frequency currents, after being amplified by the valve *V1*, are selected by the primary of the first I.F. transformer *T2* tuned by *C3* and passed to the second I.F. amplifier stage.

The usual difficulties encountered in making a valve amplify low frequency and high frequency currents at the same time, namely, the tendency of the low frequency peaks to make the grid positive with consequent distortion, are not present in the arrangement shown in Fig. 10. This is because the I.F. currents applied to the valve *V1* are of only small magnitude. One advantage of the arrangement is that direct reception of long wave stations by the intermediate amplifier is greatly reduced by the coil *L1* being connected in parallel to the frame aerial, and acting as a by-pass to the lower frequency currents.

THE INFRADYNE

An interesting innovation was proposed by H. Green in the *Radio News*, an American journal, in 1926. Green's idea was

that, since with the normal superheterodyne receivers a great deal of background noise was heard, and considerable trouble was caused by second channel and harmonic interference, an improvement on the normal superheterodyne circuit would be obtained by using an intermediate frequency that was the *sum* of the local

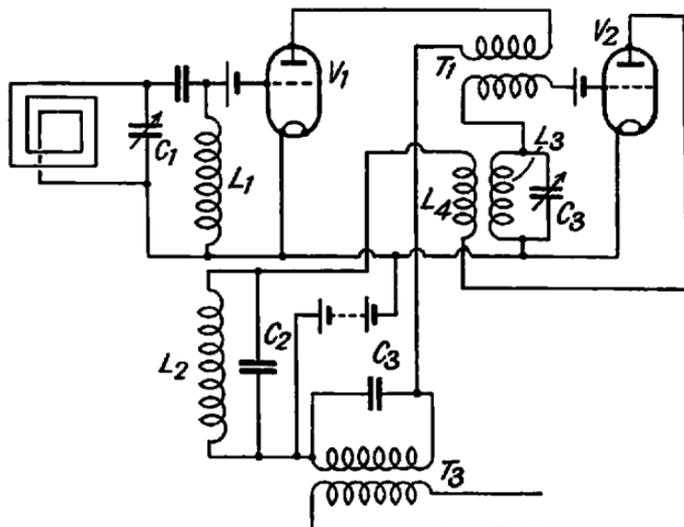


FIG. 10. ARMSTRONG'S COMBINED SIGNAL FREQUENCY AMPLIFIER, FREQUENCY CHANGER, AND I.F. AMPLIFIER

and incoming oscillations instead of the difference. A receiver was designed on these lines, and was called the "Infradyne."

It consisted of a two-stage signal frequency amplifier, first detector, oscillator, three-stage short-wave amplifier tuned to 95 metres, second detector, and two low frequency amplifier stages.

The fundamental principle on which the superheterodyne is based, namely, that the incoming frequency is converted to a super-audible *lower* frequency to facilitate its amplification and separation from other signals, is completely ignored in the design of the Infradyne. An intermediate amplifier tuned to a frequency of over 3000 kc/s (a wavelength of 95 metres) requires extremely good design to be effective, and even then must suffer from inherently poor selectivity. For example, if reception is taking place on 1000 kc/s (300 metres) and interference is experienced from a transmitter working on 950 kc/s, the percentage off-time of the interfering station falls from 5 to 1.6 when the frequency

is changed from 1000 kc/s to 3000 kc/s, and it will be extremely difficult to separate the stations.

The infradyne possessed the definite advantage in the comparatively early days of eliminating trouble due to oscillator harmonics. It also eliminated the interference due to two stations beating together to produce the intermediate frequency.

BEGINNING OF PRACTICAL DEVELOPMENT OF THE SUPERHETERODYNE

By this time (1926) the need for selective receivers in America was becoming greater each month, owing to the rapidly increasing number and power of the American broadcast stations. The average American listener desires a far more powerful receiver to be able to enjoy the pick of his national programmes than does an European listener, owing to the much greater expanse of the United States. Selectivity must, of course, be made sharper to correspond with the longer range of the receiver and its consequent ability to pick up a larger number of stations. For this reason then, the superheterodyne was developed in the United States earlier than in Europe.

A great impetus in the development of the broadcast superheterodyne receiver was given by the advent of low consumption or dull-emitter valves in 1926. These valves only required about one-quarter of the filament current necessary for their predecessors and thus eliminated one of the serious drawbacks of the home superheterodyne. In fact, the dull emitter valves went far to make the superheterodyne a practical proposition from the listener's point of view.

The growing demand for the superheterodyne receiver had a temporary set-back by the introduction of the screen-grid valve in 1927. This valve enabled a much more stable H.F. amplifier to be constructed, and diminished the need for carefully and expensively designed neutrodyne receivers. Added to these advantages was an increase in stage gain, and thus in the number of distant stations receivable.

Conditions in the broadcast band of frequencies became continuously more crowded, however, and the tuned screen-grid amplifiers proved to be unable to give the long range and high selectivity demanded by the American listener. The superheterodyne up till this time had suffered from the production of a multiplicity of whistles and interference not present in other types of receiver. These troubles greatly reduced the effective selectivity. It also was quite usual for a powerful station to be received at several settings of the tuning dials owing to the presence of harmonics, and this further lowered the selectivity. An additional drawback as compared with a straight receiver was the necessity

for two tuning controls (oscillator and signal frequency circuits). Straight receivers had only one tuning control.

All these problems were tackled seriously, and it was found practicable to manufacture an all-electric single-dial superheterodyne receiver with high effective selectivity. The actual means employed are described in Chapter IV, but it might be mentioned here that the choice of a higher intermediate frequency had a beneficial effect on the working of the receiver. Previous to 1928 an intermediate frequency of 40 kc/s or 50 kc/s was in common use. Although this frequency enabled a very stable and selective amplifier to be constructed, it made the receiver very prone to

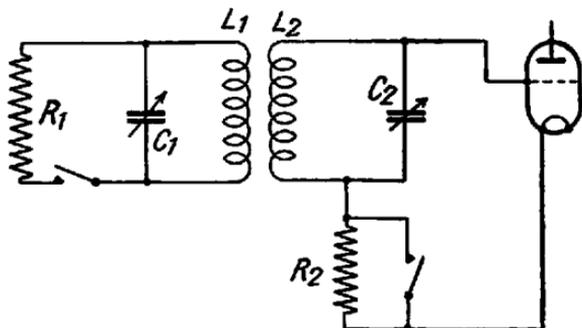


FIG. 11. CIRCUIT ARRANGEMENT FOR VARYING THE SELECTIVITY/FIDELITY CHARACTERISTICS OF A RECEIVER, USED IN AMERICA IN 1931

second channel and certain other forms of interference described in Chapter IV. The intermediate frequency that was decided upon as being the most successful compromise between stability and selectivity on one hand, and interference on the other, was 180 kc/s.

Quality of reproduction was a subject that required careful investigation, for the early types of superheterodyne receivers were particularly poor in this respect, owing to the sharp selectivity reducing the intensity of high notes. A method of overcoming this that was adopted by more than one American manufacturer is shown in Fig. 11. The coils L_1 and L_2 of the intermediate frequency transformer are tuned by condensers C_1 and C_2 respectively, and form two coupled tuned circuits. For distant reception this arrangement is highly selective, but for reception of the strong local stations such selectivity is not required. To enable the listener to obtain better quality on local reception, resistances R_1 and R_2 are controlled by switches, the former being in shunt to the tuned primary circuit and the latter

in series with the tuned secondary circuit. When these resistances are joined into circuit the gain of the stage is reduced to about one-twentieth of that given when they are out of circuit, but at the same time the tuning peaks are flattened very considerably and a band-pass filter effect is obtained. The other intermediate frequency transformers were tuned and coupled to give a band-pass effect, and no resistances were connected. In conjunction with the arrangement described, tone correction was employed.

THE DEMAND FOR THE SUPERHETERODYNE IN EUROPE

In Europe the superheterodyne receiver has had a checkered career. The difficulties militating against its popularity in America in the early days of broadcasting, as already described, were apparent on this side of the Atlantic. A design of superheterodyne receiver was described in the *Wireless World* in 1923, but interest shown by wireless amateurs in general soon faded.

There was, in fact, very little demand for a highly selective receiver in Europe, at that time, because there were comparatively few high-powered broadcast stations in commission. Interference was not a major problem, and the high frequency amplifiers then available gave results that satisfied most requirements. The neutrodyne circuit and, later, the screen-grid valve, helped to postpone the coming into favour of the superheterodyne receiver in Europe as they had done in America. A sudden large increase in the number of transmitting stations during 1930-31 brought about a greater inquiry for a more highly selective receiver. Even in 1932, however, the number of superheterodyne receivers manufactured was small compared with the total of all types, owing to their high cost in relation to the popular three-valve receiver consisting of a high frequency amplifier, detector, and output stage.

The year 1933 can be claimed as the period in which the superheterodyne definitely established itself as the most popular receiver in public demand in Great Britain. This was brought about partly by the more general appreciation of the qualities of superheterodyne reception, and also by the improved circuit arrangements and valves which enabled three- and four-valve receivers of this type to be manufactured successfully, thus bringing the cost down considerably.

THE POSITION TO-DAY

The proportion of superheterodynes to all other types of receivers at present being bought by the public is very large. This is due to the high efficiency attainable with the modern superheterodyne receiver. A scientific arrangement of band-pass intermediate frequency transformers enables first-class quality of reproduction to be obtained; band-pass signal frequency circuits

reduce a variety of interference particular to the superheterodyne; single-valve frequency changers can now be used that do not produce troublesome harmonics and radiation, and which give an appreciable stage gain; the diode rectifier gives distortionless detection; and automatic volume control enables pleasurable reception of distant stations to be obtained.

A development that has created a great interest is the single-span receiver. This receiver, which is described in Chapter VII, was evolved in the research laboratories of the *Wireless World*, and particulars of the design were published in various issues of that periodical. The basic principles of the single-span receiver, however, had been covered by patents some years before the actual design was developed. British Patent No. 243,371 (Marconi's), dated 20th November, 1924, for example, covers a method of coupling an aerial to the receiver through a filter designed to avoid second channel and similar interference; and Patent No. 301,493 (Kramolin), dated 1st December, 1927, claims the use of an aperiodic aerial coupling circuit with a local oscillator with the express object of attaining a single dial control, and outlines the method of selecting the intermediate frequency so that possible disturbing waves lie outside the reception band.

Full credit must, nevertheless, be given to the *Wireless World* for being the first to design a single-span receiver and introduce it to the British public.

Recently introduced valves have enabled manufacturers to supply the market with three-valve superheterodynes of a very high order of selectivity and quality of response. Automatic volume control can be employed satisfactorily in a three-valve receiver incorporating a double-diode-pentode. The advent of the latter, in fact, brings well within the realms of probability the manufacture of a two-valve superheterodyne radio-gramophone—using a pentagrid and a double-diode-pentode—which will include quiet A.V.C.

Car radio has been developed to the stage of practical accomplishment, utilizing the superheterodyne principle. Straight receivers are not very practicable for car radio, and by no other means than a superheterodyne circuit is it possible to obtain the required degree of amplification within the limited space available for the set.

All-wave superheterodynes have now enabled the listener to choose his station from almost any part of the world. Five separate tuning ranges are provided in some of these all-wave receivers, and the number of alternative programmes available must run into hundreds.

CHAPTER III

THE GENERAL PRINCIPLES OF SUPERHETERODYNE RECEPTION

The Heterodyne Process. For a complete understanding of the working of a superheterodyne receiver, it is essential that the reader be thoroughly well versed with the technical aspects of the process known as "heterodyning." This is the combination of high frequency currents of two different frequencies to form currents of a third frequency. Heterodyning is very commonly observed during broadcast reception, and makes itself apparent by producing a whistle, which is usually high pitched. In this case the two high frequency currents that are combined are the two incoming signals interfering with each other, and the third resultant frequency is the audible high pitched whistle, usually termed "heterodyne whistle."

Now examine more closely the actual process of combining these two high frequency currents to produce a third. Suppose the receiver in which the heterodyne whistle is formed is tuned to station *A* working on a frequency of 1000 kc/s, and an adjacent transmission channel used by station *B* has a frequency of 1009 kc/s. The difference-frequency is therefore 9 kc/s. (The term kc/s is an abbreviation of "kilocycles per second," one kilocycle being 1000 cycles.) When currents induced in the receiver input circuit by station *A* at 1000 kc/s are combined with currents induced by station *B* at 1009 kc/s, a current equal in frequency to the difference between these two is produced, and consequently, after this third frequency current is rectified by the detector, a 9 kc/s note is heard. This difference-frequency is known as the *beat frequency*, and the principles applicable to its formation are just the same as for the formation of musical beats by combining two audible notes.

The easiest way to understand exactly what happens when these two high frequency currents are induced into a common circuit, is to consider the series of curves shown in Fig. 12(a). For the sake of clearness the number of cycles of the currents represented in the figure are 20 and 22 respectively, but the same principles hold good no matter what the actual number of cycles happens to be.

In Fig. 12(a) the strength or amplitude of the current is measured along the axis *OY*, and time in seconds along the axis *OX*. The values of amplitude above the line *OX* can be considered as positive, and the values below this line as negative.

The complete fluctuations for one period are shown in the figure: that is to say, curve *a* has twenty positive peaks and twenty negative troughs, while curve *b* has twenty-two positive peaks and twenty-two negative troughs. Both currents are assumed to reach the same maximum amplitude.

It is a basic law in electro-magnetic theory that when two currents are combined in a circuit the resultant current is equal to

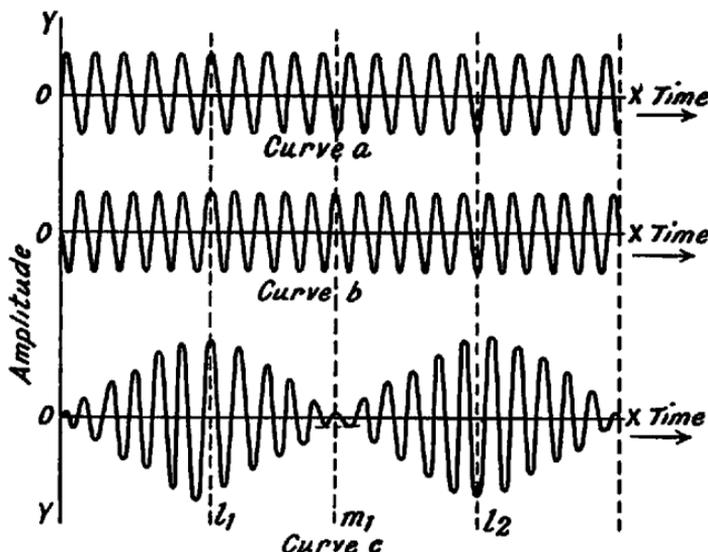


FIG. 12 (a). CURVES ILLUSTRATING THE EFFECT OF COMBINING TWO CURRENTS OF DIFFERENT FREQUENCY

their algebraic sum. In other words, if one current has three units of strength in the positive direction, and the other has three units of strength in the negative direction, then the resulting current is zero, for these currents are equal in amplitude but opposite in sign, and so must neutralize each other. In the other extreme, if one current has a value of three units positive while the other current strength is also three units positive, the sum of the currents will be six units. In this case, the currents assist each other.

Now consider how this fundamental principle affects the two currents we are considering. Referring to curves *a* and *b*, it can be seen that at certain points along the time basis *OX* the two curves are at maximum values on the same side of the line *OX*. Two of such points are indicated by the broken lines *l*₁ and *l*₂. At these points, therefore, the resultant curve must be a maximum

and equal to the sum of the two individual curves *a* and *b*. This is shown in curve *c* representing the resultant currents. At other points along the axis *OX* the two curves *a* and *b* are at maximum values but on *opposite* sides of the axis. These are the conditions for zero resultant current, and the point at which they occur is indicated with the broken line m_1 , the corresponding current represented by curve *c* being a minimum.

Curve *c* represents a current whose envelope rises to a maximum and then falls to zero again, twice in one interval of time, this frequency being equal to the difference between the respective frequencies of the component currents. One complete rise and fall is termed the beat frequency. It will be noted that during one beat the current rises and falls the same number of times as curve *b*.

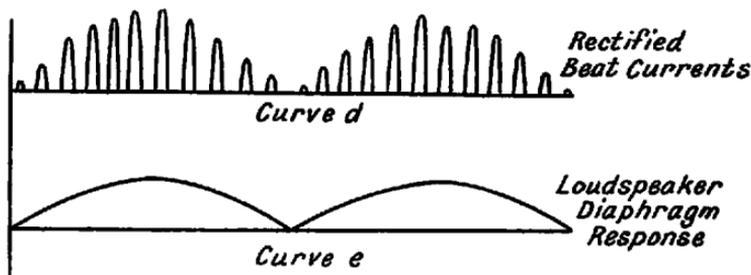


FIG. 12 (b). THESE CURVES SHOW THE RESULT OF RECTIFYING HIGH FREQUENCY CURRENTS OF THE TYPE REPRESENTED BY CURVE *C* IN FIG 12 (a)

It has already been mentioned that the principle of the formation of beat currents can be applied to any currents, no matter what their frequency. To refer again to the high frequency currents causing the heterodyne note in the broadcast receiver, it can now be seen why a 1000 kc/s current, when combined with a 1009 kc/s current, produced a 9 kc/s beat note—the current formed by the two incoming signals rose and fell at a frequency of 9000 cycles per second in a similar manner to curve *c*, Fig. 12 (a).

The rise and fall of a beat current, however, is not sufficient by itself to produce an audible result in the loudspeaker or other reproducing unit. From curve *c*, Fig. 12, it will be noticed that the beat current has the same amplitude on one side of the zero line *OX* as on the other. If the current values on one side exactly balance those on the other, the *average* current will be zero. Since the loudspeaker responds to the mean value of current flowing through it, the result of such a state of affairs will be silence.

In order to render the beat frequency audible, part or the whole

of one-half of the current represented by curve *c* must be cut off, so as to render the energy into a series of unidirectional impulses capable of actuating the loudspeaker. This action is performed by the rectifier, which transforms the current form into that depicted by curve *d*, Fig. 12 (*b*). The energy now appears as a number of half-waves. Each half-wave by itself is ineffective in causing the loudspeaker diaphragm to vibrate, for it does not possess sufficient power; but even if there were sufficient energy in the individual impulses to actuate the diaphragm, they would not do so, for the mechanical inertia of the latter would not permit it to vibrate at such a rapid frequency (the carrier frequency). The net result of these conditions is that the series of unidirectional impulses provided by the rectifier are integrated by the loudspeaker diaphragm, which responds to their group frequency as illustrated at *e*.

So far only the practical case of heterodyne interference between two incoming signals has been considered. Suppose that, instead of two incoming signals being combined together in the receiver, only one signal is received, and the second frequency is supplied by means in the receiver itself, say, by an oscillation generator. The conditions now are exactly similar so far as the production of a beat frequency is concerned, for we have two currents of different frequencies fed to a common circuit. All the effects explained above take place in precisely the same manner, and the result is the formation of an audible beat frequency equal to the difference between the incoming signal and the locally applied oscillations.

This method of reception is called the *heterodyne* system, and the local oscillator is termed the heterodyne. A heterodyne receiver as considered up till now is only of use for telegraphic signals, with which communication takes place by a series of short and long transmissions, rendered by the receiver into a series of short and long notes of the beat frequency. The reception of telephony would be quite impracticable by this method, for the audible beat note would be heard through the signal and produce intolerable interference. Heterodyne reception as described in Chapter I was successfully developed over twenty years ago, and is still used a great deal in commercial services for continuous wave telegraphic communication.

THE SUPERHETERODYNE PRINCIPLE

When an oscillation generator at the receiver supplies one of the high frequency currents required to produce a beat current, means are made available for effecting a variation in frequency of the beat. The frequency generated by an oscillator valve is varied readily by a tuning condenser in the circuit determining

the frequency produced, as explained in more detail later in this chapter. There is thus available a means for obtaining almost any beat frequency that may be desired. If, for example, the incoming signal frequency is 1000 kc/s, and the locally generated oscillations have a frequency of 1250 kc/s, then the beat frequency will be 250 kc/s. A frequency of this order is quite inaudible, because the highest frequency the ear can translate into sound is about 12 kc/s. It should be noted that when the incoming 1000 kc/s current is converted into a 250 kc/s beat current, the latter will still retain all the modulation characteristics of the original 1000 kc/s current, in the same way that the beat current represented by curve *c*, Fig. 12(*a*), still retains the fluctuations of the current *b*. If this beat frequency is rectified, then, it will be equivalent, as far as the subsequent receiver circuits are concerned, to an incoming signal on a carrier of 250 kc/s, and it can be amplified and rectified in the usual way. This inaudible beat frequency is usually called the *intermediate frequency*.

This is the fundamental principle of the superheterodyne receiver. It is found that by converting the incoming frequency to one much lower, not only is greater selectivity obtained, for the reasons explained a little further on, but a much more stable receiver can be built. Furthermore, since the amplifier can be made so much more stable at the comparatively low intermediate frequency, a larger number of amplifier stages can be used, and consequently a greater overall gain obtained. The reasons for these advantages of the superheterodyne receiver are fully discussed in the first chapter, which should be referred to again, if necessary.

There is a limit, of course, to the total amplification obtainable with this receiver. The limiting factor is background noise due to a multiplicity of causes, as explained later, but mainly to the hiss from the oscillations that must be superimposed on the incoming signals to produce the intermediate frequency. Even with this limitation, however, much greater amplification can be obtained with the superheterodyne receiver than with a straight-forward arrangement.

A schematic diagram of a typical superheterodyne receiver is shown in Fig. 13. Signal voltages on the aerial are applied to the input tuning circuits (TC) which select the desired signal clear of undesired ones. The selected currents are then passed to the circuit to which the local oscillations generated at *O* are also applied. This is usually called the *mixer circuit*. After the local and the incoming high frequency currents have been combined they are fed to the first detector or mixer valve *D1*. As already mentioned, the resultant beat frequency after combining the local and the incoming currents is above audibility, usually

about 125,000 cycles in Britain, and after rectification this intermediate frequency is amplified at *A1*, which is a tuned amplifier to help further to separate the desired from interfering signals. From amplifier *A1* the intermediate frequency currents pass to the second detector *D2* to be again rectified and made of an audible frequency. These low frequency currents are amplified in the usual manner at *A2* and applied to the reproducer *R*.

This is an outline of the practical method of reception employing the superheterodyne principle. The method applies to all superheterodyne receivers, although, of course, they are modified very considerably in the different designs. For example, between the aerial and first detector of a large number of receivers is connected a high frequency amplifier. In some designs, no intermediate

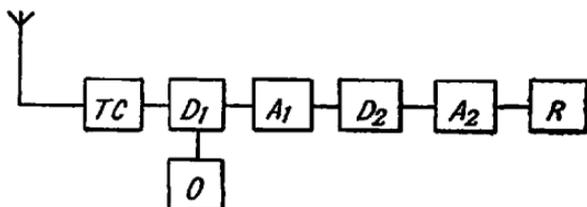


FIG. 13. SCHEMATIC ARRANGEMENT OF THE VARIOUS CIRCUITS USED IN A SUPERHETERODYNE RECEIVER

frequency amplifier *A1* is used, but instead, the first detector *D1* is coupled to the second detector *D2* by circuits tuned to the intermediate frequency. Quite a large number of receivers use only one valve for first detector and oscillator, instead of having a separate oscillator as shown in Fig. 13. In all cases, however, the principles underlying the working of the various types of superheterodyne receiver are the same, notwithstanding the various modifications adopted by the different designers.

In order to see exactly what is happening in the several parts of the receiver, the character of the currents in each unit must be considered. Still referring to the hypothetical case shown in Fig. 13, a series of curves is drawn in Fig. 14 which show the state of the incoming and combined currents at each part of the receiver from aerial to loudspeaker.

Curve *tc* represents the incoming carrier wave after it has been selected by the tuned circuits at *TC* from the gamut of high frequency voltages fed to the receiver by the aerial which, when reception is taking place on 300 metres, has a frequency of 1000 kc/s. The oscillations produced by the local generator *O*, say 1100 kc/s, is depicted by curve *o* and, after these have been superimposed on the incoming signals, a current as shown by

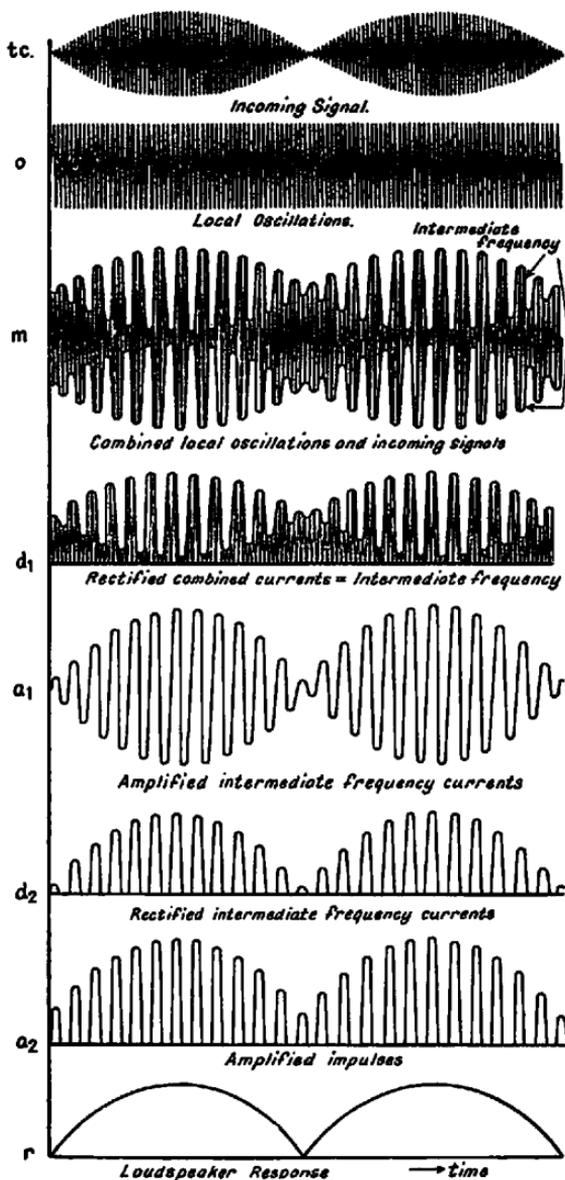


FIG. 14. SERIES OF CURVES DEPICTING THE TYPE OF CURRENT IN THE VARIOUS PORTIONS OF A SUPERHETERODYNE RECEIVER

curve m is produced in the manner already discussed. This combined current is rectified at $D1$ to form beats as seen as $d1$, these beats being above audibility and known as the intermediate frequency.

The frequency changing process can be clearly seen from m . The high frequency current curve is varied on both sides of its envelope at a rate depending upon the difference between the frequencies of tc and o . After rectification there remains the intermediate frequency which carries the original modulation of the incoming signal at tc . So far as the reception process is concerned, therefore, the modulated intermediate frequency current is equivalent to the incoming signal of a straight receiver.

It can be proved mathematically and experimentally that when one current of frequency n_1 is superimposed on another current of frequency n_2 , there results after detection not only a current of a frequency equal to $n_1 - n_2$, but also another of frequency equal to $n_1 + n_2$. One consequence of this is that in the circuits between the two detectors there is the choice of two frequencies, one being equal to the *sum* of the incoming and the locally generated frequencies, and the other to the *difference* of these currents. For reasons that will be apparent after a perusal of the first chapter, the difference frequency is usually chosen, and in the case now being considered it will be supposed that the intermediate frequency amplifier is tuned to select the difference frequency between the 1000 kc/s incoming signal and the locally generated 1100 kc/s oscillation, i.e. 100 kc/s.

The intermediate frequency is amplified at A as seen from curve $a1$, and in this state it is applied to the second detector. A detector is necessary at this stage because at $a1$ the currents fluctuate equally on both sides of the zero line. Such a current, if applied to an ordinary acoustical reproducer such as a loudspeaker, would not produce any sound owing to the fact that the loudspeaker could not respond to such a high frequency current. Although this frequency is low in comparison to the incoming signal, it is high compared with audible frequencies, since it is still the supersonic intermediate frequency.

The amplified intermediate frequency is applied to the second detector $D2$ and rectified to produce low frequency currents of the form shown at $d2$. These L.F. currents after amplification at $A2$, curve $a2$, are applied to a reproducer such as a loudspeaker, the diaphragm of which responds as indicated by curve r .

Advantages of Fixed Intermediate Frequency. It will be clearly apparent from the above outline of the operation of the superheterodyne receiver, that one important difference between this type of receiver and the normal straightforward arrangement is that in the former the main radio frequency amplification is

carried out at a single fixed frequency quite independently of the incoming signal frequency, whereas in the straight receiver all the radio frequency circuits are tuned to the signal frequency itself. Due to this, it is possible in a superheterodyne receiver to adjust the intermediate tuned circuits at the factory for the most satisfactory operation, and, once they have been properly set, no further adjustment is necessary. This tends to make the superheterodyne very robust.

A further advantage of having a fixed frequency for the amplifier is that the maximum efficiency can be obtained from the tuned circuits. When an amplifier has to respond to a wide range of frequencies, as is necessary, for example, in a broadcast receiver, it is impracticable to construct a tuned circuit, consisting of inductance coil and tuning condenser, that will possess the same dynamic resistance at all the frequencies to which it has to be tuned. Consequently, a greater amplification will be obtained during reception of some stations than others of different frequency, and an uneven overall response is obtained unless special measures are taken to compensate this phenomenon. In the superheterodyne receiver, the main amplification is usually carried out at the intermediate frequency which is constant irrespective of the frequency being received, and so the uneven amplification due to the tuned circuits is not present. Some types of receivers, such as the Kolster Brandes model described in Chapter VII, do not employ an intermediate frequency amplifier at all. Receivers of this kind are considered worth while, however, owing to the gain in selectivity that they possess over a straight receiver of equivalent cost or amplification.

The Selectivity of the Superheterodyne. One of the main considerations in the design of a broadcast receiver at the present time is the ability of the receiver to select the H.F. voltages due to the desired station, clear from the voltages induced in the aerial system by other stations. This is known as *adjacent channel* selectivity, because the most troublesome interfering stations are usually those working on a frequency close to that of the desired station. It is necessary to distinguish between interference due to this cause and the interference that can result from the several imperfections in design explained in Chapter IV, such as second channel interference, beat interference, etc.

The adjacent channel selectivity of the superheterodyne receiver is the main cause of its popularity. This ability to cut-out interfering stations is due to the employment of the intermediate frequency circuits, which can be made much more efficient than others that have to respond to a large range of frequencies, for the reasons mentioned above. An additional and very important gain in selectivity is obtained from the inherent quality of tuning

at lower frequencies, which enables the circuits to be far more selective than if the amplification is carried out at the high signal frequency.

Now consider how this is brought about. One important factor in the selectivity obtainable with any tuned circuit is the frequency to which it is tuned. A circuit tuned to a low frequency will be more selective than another circuit of the same efficiency tuned to a high frequency. This is because the ability of a circuit to select currents of one particular frequency depends upon the percentage difference in frequency between the desired and the interfering currents. This can be best explained by taking a numerical example. Suppose the local generator is delivering oscillations at 1000 kc/s and the desired signals have a frequency of 900 kc/s. An interfering station working on an adjacent channel may have a frequency of 910 kc/s; that is to say, 10 kc/s different to the desired frequency. Now the percentage the interfering station is off-tune in the high frequency circuits is $\frac{10}{900} \times 100 = 1.1$ per cent, and it will be difficult, with straightforward tuning arrangements, to select the desired signal if the interfering signal is much stronger than the required signal.

Suppose that both these signals have been passed through to the intermediate frequency amplifier. The desired signal frequency has been changed to 100 kc/s (1000 kc/s - 900 kc/s) and the interfering frequency to 90 kc/s (1000 kc/s - 910 kc/s). The percentage off-tune has now jumped to $\frac{10}{100} \times 100 = 10$ per cent. This demonstrates that it will be nine times easier for the interfering station to be rejected by the superheterodyne receiver with a 100 kc/s intermediate amplifier than if the currents were all tuned to the signal frequency. On the other hand, if a higher value of intermediate frequency were employed, say 500 kc/s, the oscillator would have to generate a frequency of 1400 kc/s in order to receive a 900 kc/s station. The interfering station referred to would then have a frequency of 490 kc/s when it reached the intermediate frequency amplifier, and so the percentage off-tune would be $\frac{10}{500} \times 100 = 2$ per cent. In the latter case, therefore, the selectivity would be only slightly improved.

The frequency chosen for the intermediate frequency amplifier thus has a direct bearing on the selectivity of the receiver; the lower the frequency, the greater being the adjacent channel selectivity.

An intermediate frequency circuit is just like an ordinary high frequency circuit. Its nature and function is, in fact, the same

as a signal frequency amplifier circuit, the only difference being that usually it is tuned to a lower frequency than the signal. The intermediate frequency current consists of a carrier component and a modulation component just the same, except in carrier frequency, as the original signal impressed on the aerial, and this must be rectified by the second detector in order to obtain audible signals. The second detector, therefore, performs a similar function to the detector of a straight receiver.

In Chapter VII a number of modern designs of superheterodyne receivers are described, using from three to twenty-five valves. These receivers have been selected as representing the modern trend in superheterodyne receiver design. By examining these circuits, all of which present novel features, a complete insight into the working of this interesting type of receiver may be gained. A hypothetical receiver circuit could have been included in this chapter for completeness, but the writer prefers to confine the circuit descriptions to practical present-day models.

The Generation of Oscillations. This chapter on the theory of superheterodyne reception would be incomplete without reference to the method of producing oscillations, for the *local oscillator*, as the oscillation generator in the receiver is called, forms a vital part of the receiver. The actual circuits used for working a valve as an oscillation generator are very numerous, and only the fundamental theory is described in this chapter. There are a number of practical modern combined oscillator-detector circuits described in another section of this book, and a study of these, together with the circuits outlined in Chapter VII, should enable a sound knowledge of the practical application of the theoretical considerations mentioned below to be obtained. In addition to the modern circuits described in Chapter VII, a number of oscillator arrangements have been outlined in Chapters I and II. These are mostly of historical interest, but once the principles of oscillation generation have been understood, the earlier circuits and their application will make interesting and helpful reading.

There are various ways of producing high frequency oscillations. They can be generated, for example, by a high frequency alternator, or an electric arc. These methods, however, are of no practical value for superheterodyne reception, and will not be considered.

The thermionic valve, however, can be used in a variety of ways to generate oscillations. One method is to operate it as a dynatron in which the anode circuit represents a negative resistance due to the secondary emission of electrons by the anode. This type of oscillation generator, also, is not used as the local oscillator of the superheterodyne, and so will not be further referred to.

The method of generation that is employed universally for the

local oscillator is that known as the *feed-back* method. In this arrangement, a certain amount of energy is fed back from one circuit to another in such a way that the valve is set into self-oscillation. As this type of generator is used in one form or another in every superheterodyne receiver, it is important that its operation be clearly understood.

In Fig. 15 is seen a simple circuit for the generation of oscillations. The grid or input circuit comprises inductance coil $L1$, tuning condenser, the grid-cathode path inside the valve, and the connecting wires. The anode or output circuit consists of coil $L2$, battery, filament switch, the cathode-anode path inside the valve, and the necessary connecting wires. Inductance $L2$ corresponds to the reaction coil of the average broadcast

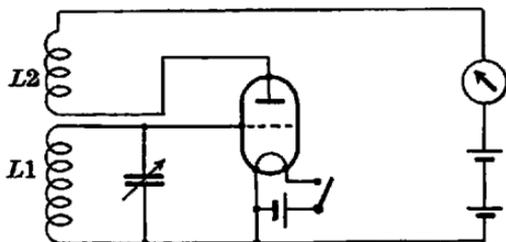


FIG. 15. OSCILLATION GENERATOR USING FEED-BACK PRINCIPLE

receiver. Every listener knows only too well that when reaction is increased beyond a certain point the set is thrown into oscillation.

For a full understanding of the process of generation it is necessary to start investigation at the time the valve is cold and unconnected. There is then no current flow in any of the circuits. When the filament switch is closed the cathode becomes heated and emits electrons which, owing to the comparatively high positive voltage on the anode, are attracted by the latter. Once these electrons have reached the anode they strive immediately to return to the source from which they came, and so a steady current will flow round the external anode circuit from the anode of the valve, through coil $L2$, and battery to the cathode again.

Now when a current flows round a coil of wire it sets up a magnetic field. The nature of this field is of no concern here. What is of interest, however, is the fact that this magnetic field is capable of inducing a voltage in another coil of wire if the latter is placed close by. As a result of the current flow round coil $L2$, then, a voltage will be induced in $L1$, if these two coils are situated fairly close to each other. This process, known as *induction*, can only

take place so long as the strength of the current in $L2$ is varying. The voltage induced into $L1$ charges the grid of the valve, and, if the coil $L2$ is the right way round with respect to $L1$, this charge will make the grid more positive. This accelerates the rate of flow of electrons from the cathode to the anode, which increases the current flowing to $L2$ to above its steady value. When the increase in anode current as a result of the positive induced charge on the grid ceases, the magnetic field round $L2$ collapses. This induces a voltage in $L1$ again, but this time of an opposite sign to that previously induced, and so the grid becomes negative. A negative grid, however, retards the flow of electrons, and so the anode current will diminish until it reaches a minimum value below normal. With the anode current at minimum no induced negative voltage is applied to the grid, so the latter is allowed to return to its normal voltage. This again permits the anode current to increase and the series of events begins once more. Each anode current swing to a value above and below normal is a little greater than the previous one, owing to the fact that as the anode current increases the induced grid voltage also is made greater, thus producing a cumulative effect.

This give-and-take process between grid and anode circuits, which is termed feed-back because energy is fed back from the output to the input circuit, goes on until a state is reached in which the maximum current the operating conditions will allow is flowing in the anode circuit. For the generation of oscillations the voltages applied to the valve are adjusted to the values which cause the feed-back to be so strong that oscillating currents in the grid and anode circuits are self-maintained, the energy being supplied by the anode battery. The maximum amplitude of these oscillations is determined by the plate voltage and the cathode emission.

The actual anode current and grid voltage changes can be best visualized by an examination of the curves shown in Fig. 16 which represent them. From these curves it is seen that when the anode current reaches a certain value, at point p along its anode current curve, a voltage is induced on to the grid and makes the latter positive. The positive grid increases the anode current to the first maximum point $m1$, when the anode current begins to diminish. In falling, the anode current goes past the normal steady value corresponding to the point p as indicated by the broken line, and induces a negative voltage on the grid which further reduces the anode current to the minimum value $m2$. It will be noticed that the point $m2$ is a little further away from the working point p than $m1$. After the minimum $m2$ has been reached the grid returns to its normal potential, and the anode current again rises, passes the normal working value, and attains a new high level

m_3 which is greater than m_1 . This series of current rises and falls goes on as shown until the maximum peaks M are reached, at which the valve is generating a self-maintained oscillatory current with an amplitude determined by the operating voltages applied to the valve.

It is clear from the curves that the voltage on the grid varies in an oscillatory manner, and this is the reason why in some valve

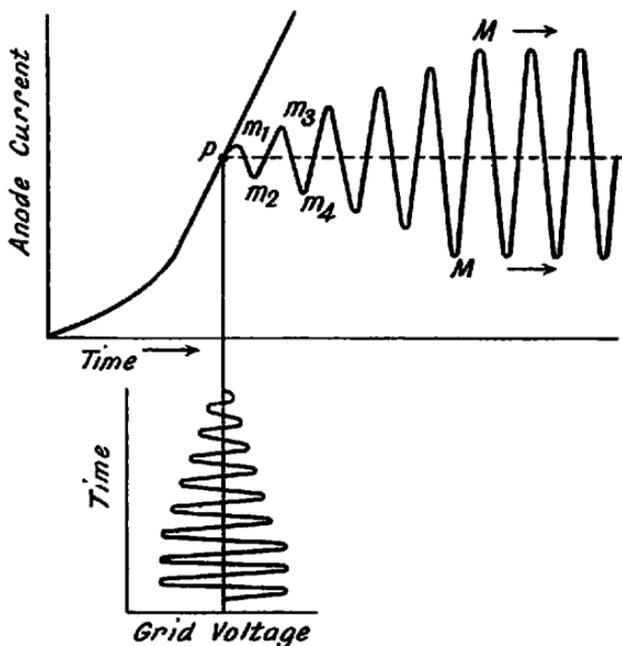


FIG. 16. CURVES OF ANODE CURRENT AND GRID VOLTAGE OF A VALVE BEGINNING TO OSCILLATE

generators the grid circuit is tuned and the anode circuit is untuned. The value of the voltage induced into the grid circuit will depend to a large extent upon the coupling between the grid and anode circuits and in practice this is adjusted to be of such a value that the grid voltage is not so great as to distort the sinusoidal shape of the anode current curve. If this coupling is too great, the anode current peaks will be flat topped, and this will produce strong harmonics, which, as will be seen later, are very detrimental to the successful operation of the superheterodyne receiver.

FREQUENCY CHANGING WITHOUT RECTIFICATION

It has been shown in the process described for the formation of the intermediate frequency that rectification is necessary. While this is true for the types of superheterodyne employed in the past, the statement needs modification in view of the process employed in the modern multi-grid frequency changers. The frequency changer is the valve wherein the local oscillations are mixed with the incoming signals to form the intermediate frequency. Until fairly recently, the frequency changer has been termed the first detector, for detection was a necessary part of its operation, and was usually performed on the curved or square law portion of the valve's grid/anode current characteristic.

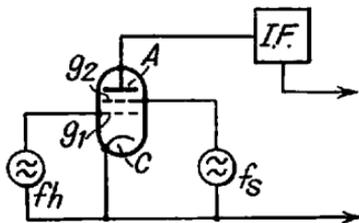


FIG. 17

Consider now the ideal case of a valve with two grids, cathode and anode, that has no inter-electrode capacity or couplings apart from the electron stream proceeding from cathode to anode. If the incoming signal oscillatory voltages are applied to the grid nearest the anode (g_2), and the local oscillation or heterodyne voltages are applied to the grid nearest the cathode (g_1), as shown in Fig. 17, then both voltages will modulate the flow of anode current. The mutual conductance of the valve, i.e. the influence that the fluctuating voltages on g_2 has on the anode current flow, will be controlled to a large extent by the heterodyne voltage applied to g_1 . It should be noted that the influence of the respective grid voltages on the electron stream and on the mutual conductance of the valve is observable whether a small bias is applied to either grid or not.

The oscillatory anode current flow is determined by the slope of the mutual conductance characteristic with reference to g_2 and A , in the first instance. In the case being considered, the instantaneous signal voltage, say V_2 , is applied to g_2 and the corresponding anode oscillatory current is $m \cdot V_2$, where m is dependent on the slope of the mutual conductance characteristic of g_2 and A . If now, the heterodyne voltage, say V_1 , is applied to g_1 , the resultant slope of the mutual conductance curve in respect of g_2 and A is a function of V_1 , and can be expressed as $m = n \cdot V_1$, where the value of n depends upon the operating and circuit conditions. We now have, writing i_a for anode current,

$$\begin{aligned} i_a &= m \cdot V_2 \\ m &= n \cdot V_1 \\ \text{i.e. } i_a &= n \cdot V_1 \cdot V_2 \end{aligned}$$

and direct multiplication is obtained. It should be noted that the mutual conductance will vary as V_1 and V_2 fluctuate into and out of phase with respect to each other.

This is the process known as frequency multiplication, the mathematics of which has been simplified to bring out the main features. The essential requirement for the operation of this method of producing the intermediate frequency is that the mutual conductance between one grid and anode must be capable of being varied by the voltage applied to the other grid. The component $n \cdot V_1 \cdot V_2$ has the desired intermediate frequency. It can be shown, in fact, that $n \cdot V_1 \cdot V_2$ not only comprises the usual *difference* frequency ($f_h - f_s$) but also the *sum* frequency ($f_s + f_h$). The method of frequency changing just described is therefore equally applicable to the infradyne type of reception (i.e. in which the sum frequency is employed as the intermediate frequency) as to the normal superheterodyne.

The process of multiplication detection can be compared with rectification in the following way. If V_1 is the instantaneous signal frequency voltage applied to a first detector valve and V_2 the heterodyne voltage also supplied to it, then these will be superimposed additively on the square law characteristic of the detector valve and the output will, therefore, be the square of the sums of these voltages, i.e.

$$(V_1 + V_2)^2 = V_1^2 + 2V_1 \cdot V_2 + V_2^2.$$

The product of the input voltages ($2V_1 \cdot V_2$) is the modulation component and contains the sum *and* difference frequencies as mentioned above. It is thus seen that in both cases the component $V_1 \cdot V_2$ is produced. In rectification, this component is produced by the square law characteristics of the valve, but in the multiplication process it is formed by the control of the mutual conductance slope of the valve by the phase of the voltages on two grids.

Practical Circuit Arrangement. It was mentioned in reference to Fig. 17 that the arrangement shown there was for the ideal case where no stray capacities or couplings existed. In practice these conditions are, of course, never possible. The notes on the formation of the intermediate frequency by multiplication detection are applicable, however, whether the valve capacities and couplings are considered or not. In any practical circuit, steps will obviously have to be taken to diminish the "strays." Consideration of this point brings us to the modern frequency changer valves known as hexodes, heptodes, and octodes.

Instead of generating the local oscillations separately and applying them to g_1 , the modern valves have two electrodes that

act in conjunction with the cathode to form the oscillation generator in the same way as any ordinary triode. The electrode that acts as anode of the oscillator is slatted so that the electrons can pass through and proceed towards the main anode *A*. Grid g_1 in Fig. 17 is thus in practice replaced by two electrodes, one of which forms the oscillator anode. To shield the oscillator electrodes from the other part of the valve, a screen electrode—also the shape of a grid—is interposed between the oscillator anode and the next grid (g_2 in Fig. 17). Between the signal grid

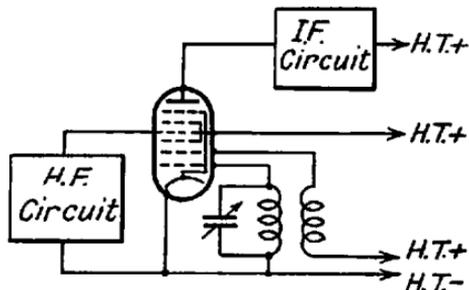


FIG. 18.

(g_2 in Fig. 17) and main anode either one screen grid, as in the usual screen grid valve, or two grids as in the H.F. pentode, may be inserted to screen the signal grid from feed-back effects from the main anode.

It should be emphasized that the production of the intermediate frequency without the use of rectification is carried out fundamentally in the same manner whether the auxiliary screens are one or three in number. In Fig. 18 is seen a diagram of a valve with two screen grids and a suppressor grid in addition to the signal grid, oscillator grids, cathode, and anode. As this type of valve has eight electrodes it is called an octode. Some valves have a similar electrode formation to this, but without the suppressor grid, and are thus heptodes or pentagrids. Another type of valve does not utilize a screen grid between signal grid and anode, the only screen grid employed being that between the oscillator electrodes and signal grid. This valve is the hexode. Both the heptode and hexode are dealt with more fully in Chapter V.

Advantages of Multiplication Detection. It has been shown that the intermediate frequency is formed by the direct multiplication of the oscillator and signal voltages when these modulate a common electron stream. When rectification is employed, however, a number of additional frequencies must necessarily be

formed during the process of producing the intermediate frequency, as is evident from the relevant formula already given. After a perusal of the following chapters of this book it will be apparent to the reader that a number of parasitic frequencies are liable to be set up in a superheterodyne receiver. Any arrangement that diminishes these disturbing currents will, therefore, be of great value for the successful operation of the receiver. The reduction in the number of whistles due to the presence of parasitic oscillations that is brought about by the employment of multiplication detection, instead of direct rectification, is one reason for the popularity of the heptode and octode valves.

CHAPTER IV

PROBLEMS OF THE SUPERHETERODYNE RECEIVER

Ganging Preselector and Oscillator Circuits. Since the broadcast bands of frequencies are fairly extensive, the preselector circuits, i.e. the circuits tuned to the signal frequency before it is transformed to the intermediate frequency, must be capable of tuning to all of these frequencies. In order that each incoming signal may be converted to the lower intermediate frequency, the local oscillator must also be adjustable so that at any given tuning of the preselector circuits the oscillator is producing high frequency

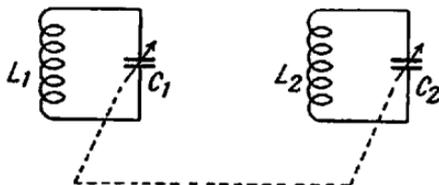


FIG. 19. SIMPLE ARRANGEMENT OF PRESELECTOR AND OSCILLATOR TUNED CIRCUITS

currents which differ from the signal frequency by the intermediate frequency. If this adjustment is not correct a very large loss of signal will result in the intermediate frequency amplifier, which is tuned to the frequency difference between the preselector and the oscillator.

The normal procedure in receiver tuning circuits is to have a fixed value of inductance in the form of a coil, and to connect to this a variable condenser. The preselector tuning coil must have a value of inductance different from that of the oscillator, owing to the fact that the circuit has to tune to a different range of frequencies. Let it be supposed that the preselector tuning must always be 100 kc/s lower than that of the oscillator. Then for the highest frequencies (with minimum amount of tuning capacity in circuit) the inductance of the preselector coil will have to be lower than that of the oscillator coil. In Fig. 19, $L_1 C_1$ is the signal tuning circuit and $L_2 C_2$ the oscillator tuning circuit. Coil L_1 is, therefore, smaller than L_2 .

It is easily demonstrated that if two coils of different inductance values are tuned by condensers of exactly the same form and

capacity, the respective frequencies of the two circuits thus formed will not vary in step. In other words, the constant frequency difference which is so necessary for the successful operation of the frequency transforming portion of the superheterodyne receiver will not be attainable.

The easiest way of overcoming the difficulty is to use a special shape of plates for one of the circuits to modify the relative tuning curves so as to compensate for the unequal frequency changes of the two circuits. This is actually done in many cases. The oscillator condenser plates are given a special shape, and it is found in practice that this enables satisfactory alignment of the two circuits to be obtained on one waveband. The problem is simplified by the use of straight-line frequency condensers.

A further problem presents itself, however, when the waveband is changed, such as when changing over from the medium waves

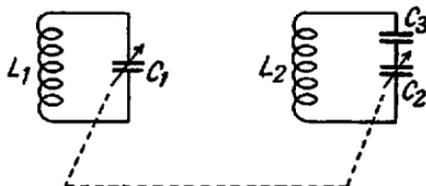


FIG. 20. PRESELECTOR AND OSCILLATOR CIRCUITS SHOWING PADDING CONDENSER INSERTED

to the long waves. Although the circuits are correctly aligned on the lower waveband, they will be badly out of adjustment on the high wavelengths. The most usual method of attaining dual waveband alignment is to connect a padding condenser in series with the tuning condenser when it is connected for long wave reception. This brings us to the second method of ganging the preselector with the oscillator circuit, known as the *padding condenser* method.

In Fig. 20 the preselector circuit is $L_1 C_1$, as before, and the oscillator circuit is $L_2 C_2 C_3$. The extra condenser C_3 is the padding condenser. As in the previous instance L_1 must have a lower value of inductance than L_2 , so that at the minimum setting of the two tuning condensers the preselector circuit is tuned to a frequency 100 kc/s lower than that of the oscillator circuit. Condenser C_3 , the padding condenser, has a capacity that is large in comparison with the tuning condenser C_2 , with the result that at the lower settings of the latter the padding condenser has very little effect. The tuning of the circuit at this end of the frequency range is thus almost entirely due to the ganged condenser C_2 .

As the capacity C_2 in circuit is increased and the deviation from the required 100 kc/s separation between circuits $L_1 C_1$ and $L_2 C_2$ above would tend to become greater, the value of C_2 approaches that of the extra condenser C_3 , and the effect of the latter becomes more apparent. The value of C_3 is so adjusted that at the maximum setting of the oscillator tuning condenser, when the normal misalignment between the two circuits without the padding condenser would be greatest, the difference in tuning between the two circuits is that required for correct ganging. It is found that with this adjustment properly carried out, the frequency difference between the circuits need never be sufficiently far from the required value to cause serious loss of efficiency.

Another method of bringing the circuits into alignment on the lower band of frequencies is to connect a compound impedance into the oscillator circuit instead of a single inductance coil. Such an impedance can consist of an inductance and resistance in series (such as a coil wound with resistance wire), an inductance and condenser in series, or a circuit coupled to the oscillator long wave tuning inductance and arranged to introduce a resistance into the latter over half the tuning range and so to flatten the resonance curve. To effect this injection of resistance, the exterior coupled circuit is tuned to a frequency that is approximately the lowest in the long waveband.

Image Signal Interference. To every frequency of the oscillator circuit there are two frequencies of the preselector circuits that are separated from it by the intermediate frequency. This means there are two incoming signals that could combine with the local oscillations to produce the intermediate frequency beats, one of these incoming being the required signal and the other the image or second channel signal. If, for example, the local oscillations had a frequency of 1000 kc/s, and the intermediate frequency of the receiver was 100 kc/s, then a desired incoming signal at 900 kc/s and an image signal at 1100 kc/s would both be able to set up intermediate frequency currents, which would be amplified and cause interference.

The elimination of image signal interference has always been a difficult problem to designers of superheterodyne receivers, for owing to a tuned intermediate frequency circuit being connected to the anode of the first detector, even a very small voltage at the image signal frequency reaching the grid of this valve will be amplified and selected by it. Trouble will also be caused if an harmonic of a strong signal happens to be of the second channel frequency. The solution of the difficulty is rendered more complicated by the continual increase in the number of transmitting stations.

The obvious method of combating this trouble is to make the

signal frequency circuits so selective that the image frequency cannot get through to the input of the first detector valve. One effective way of doing this is to have a signal frequency amplifier stage preceding the first detector, so that the desired frequency is selected and amplified relative to the unwanted frequency before being combined with the local oscillations to produce the intermediate frequency. The difference between the desired and image frequencies is twice the intermediate frequency, as can be seen from the case mentioned above where, with the oscillator set at 1000 kc/s, incoming signals of 900 kc/s and 1100 kc/s respectively produced the requisite 100 kc/s intermediate frequency. As in most modern sets the oscillator frequency is above the desired signal frequency, the image frequency is usually quite an appreciable percentage off-tune. In the instances given, the percentage is $\frac{200}{900} \times 100 = 22$ per cent, so that no serious difficulty would be encountered under normal conditions in eliminating interference due to this cause if a high frequency amplifier stage preceded the first detector.

From the above it will be observed that as the second channel signal is separated from the desired signal by twice the intermediate frequency, the higher the latter is the easier will it be to reduce this type of interference. If, for example, the intermediate frequency is 500 kc/s, then, with the oscillator at 1000 kc/s as before, and a desired incoming signal of 500 kc/s, the image frequency is 1500 kc/s. This image frequency differs so widely from the signal frequency that it would cause very little trouble. Consequently the question arises, why not have a high intermediate frequency? In the answer to this question one of the very *raisons d'être* of the superheterodyne receiver is involved.

The whole idea behind the production of the superheterodyne receiver, as described in the chapter dealing with its invention, is that it shall be able to amplify high frequency signals very selectively without causing instability difficulties. It has already been shown that the higher the frequency received the greater are the precautions that have to be taken to avoid trouble due to capacitative and feed-back effects in the valves and circuits. Stability in operation, then, is surely one powerful point in favour of using a low intermediate frequency. Although a high-gain amplifier can be constructed for a frequency of 500 kc/s if this is required for the intermediate frequency—in fact, some manufacturers use an intermediate frequency of this order—such an amplifier does not possess the high selectivity that is usually demanded of modern receivers. There are thus two opposing considerations in the choice of the intermediate frequency: stability and adjacent channel selectivity require a low intermediate

frequency, whereas image signal rejection is favoured by having a high one. A compromise has to be found, and the intermediate frequency in British sets is generally between 100 kc/s and 125 kc/s. In America a frequency of 175 kc/s is in common use.

In addition to the employment of selective signal frequency circuits, other measures are frequently resorted to by manufacturers in order to rid a receiver of image frequency interference. These usually comprise dual coupling devices for applying the voltage due to the image frequency signals to two parts of a circuit in opposite phase, but equal in amplitude so that they cancel out. In this way it is found practicable largely to reduce the whistles due to this kind of interference.

Some receivers use a small condenser connected directly between the aerial and the grid of the first detector, no H.F. amplifier being used. Through the usual tuned input circuits the desired signal currents and the second channel signals will pass together; but if the coupling elements and the capacity between aerial and grid are correctly adjusted, only the second channel voltages will pass over the latter path, and will be applied to the grid side of the input circuit in opposite phase but equal in amplitude to the interfering voltage that travelled through the signal tuning circuit. Voltages due to the second channel signal are thus neutralized. The efficiency of this arrangement is greatest for the particular frequency for which the neutralizing condenser is adjusted. The actual range over which it is of practical value depends upon the constants of the circuits with which it is employed.

When inductive coupling is employed for second channel rejection, a coil connected to the aerial circuit is coupled to one of the receiver circuits in such a way that, although the desired and second channel voltages pass through the input circuits in the normal way, only the second channel voltages are transmitted over the rejector coil. These are applied in opposite phase, but equal in intensity, to the circuit to which the rejector coil is coupled, and so the second channel signal is balanced out.

A good example of the use made of image signal suppression devices is seen in the simplified version of the circuit diagram of the G.E.C. Superhet 5 shown in Fig. 21. The image signal suppressor system is drawn with extra thick lines. The aerial coil is inductively coupled to the input band pass filter, desired and second channel signals both passing over this path together. A small condenser is connected between the aerial and the filter, and serves the purpose of providing a low impedance path for second channel signals which are applied to the filter in addition to those that pass over the inductive coupling between. The condenser is adjusted to have such a capacity that dual coupling is effected for the transfer to the band-pass filter of both the

signal and the second channel signals. Additional means to suppress second channel interference comprise a coil at the low potential end of the cathode wiring coupled to the input coil so as to cancel out voltages of the interfering frequency, and coil L in series with condenser C which tend to neutralize the second channel voltages on the grid of the frequency changer valve. A precaution against interference by I.F. currents in the L.F. circuits consists in the provision of an intermediate frequency filter across the second detector valve. This filter forms a low resistance path for signals of the intermediate frequency only.

Beat Interference. This is another type of interference caused by the carrier of an unwanted station separated a certain frequency difference from the desired station, but it is different from the second channel interference mentioned above.

In considering the act of frequency changing to produce the intermediate frequency, it has been assumed that the local oscillator supplied the high frequency currents to be superimposed on the incoming carrier wave. But suppose that instead of using the receiver generated oscillations, we use oscillations of the desired frequency supplied from an outside source, say, a transmitter. If the currents due to the transmitter are of sufficient intensity and of the required frequency, it is obvious they could replace the oscillations generated by the receiver valve and, by combining with the desired incoming signals, form the intermediate frequency. This phenomenon is known as *beat interference*.

In actual practice, of course, this is not easily done, because the transmitted oscillations to be superimposed on the desired signals have to be separated from the latter by the intermediate frequency, and therefore are so far off resonance that the voltage induced in the tuned circuits will usually be negligible. Take, for example, the reception of a station on 1000 kc/s (300 metres). The intermediate frequency of the receiver is usually about 100 kc/s, so that the frequency of the transmitted oscillations required to beat with the desired incoming must be either 900 kc/s or 1100 kc/s. The percentage off-tune is, therefore, 10 per cent, and with modern high efficiency circuits this is sufficient to cause voltages induced by any but a local transmitter to be reduced to harmless dimensions.

From the foregoing it might appear that reception is possible by taking advantage of beat interference and shutting off the receiver local oscillator. This, however, is not the case, for a transmitter sends out not only a carrier wave but sidebands as well. Consequently, since two signals are combined to form the intermediate frequency, there will appear in the intermediate frequency amplifier two signal currents and reception will be spoilt.

The cure of beat interference clearly consists in having efficient preselector circuits, for the more selective they are, the less will be the voltage induced by an interfering station at a given frequency of resonance. This is one advantage of having a signal-frequency amplifier between the aerial and the frequency changer circuits.

Beat interference is not a major trouble with the superheterodyne receiver. For one reason, it only occurs in a receiver with poorly selective high frequency circuits, or at places situated close to a transmitting station; and a second reason is that even under fairly bad conditions beat interference will only take place on a few positions of the tuning dial.

It is important, however, that the intermediate frequency should be so chosen that it is not equal to the difference between the frequencies radiated by two local stations.

If anything is done to reduce temporarily the selectivity of the signal frequency circuits, beat interference may be experienced. When the full sensitivity of the receiver is employed, for example, it is possible for a local transmitter to cause sufficient grid current to flow to damp the input circuit to the first detector and thus reduce its selectivity. In these circumstances beat interference may result.

Intermediate Frequency Harmonics. One type of intermediate frequency harmonic trouble is that due to wave form distortion by the second detector. Owing to its non-linear characteristic the second detector invariably produces harmonics of the intermediate frequency carrier current, and if these interact in any way with the oscillator or signal frequency currents, additional interference will be produced.

Suppose, for example, a 500 kc/s signal current is being received, and the intermediate frequency is 125 kc/s. If, after rectification in the second detector, the third harmonic of the intermediate frequency (375 kc/s) is back-coupled to the signal frequency circuits, then there will be produced a beat frequency which will be amplified in the I.F. stages and interfere with the desired signal.

This difficulty was present to some extent in the earlier types of superheterodyne receiver. Designers overcame it by providing a shunt path to earth for the harmonic currents which, however, did not by-pass the signal currents. The simple expedient of connecting a high frequency choke in the second detector anode lead, as seen in Fig. 22, with a small fixed condenser connected from either side to earth, was found to be very effective in most cases. Screening is clearly of paramount importance in preventing intermediate frequency harmonic trouble, for if the anode circuit of the second detector and the L.F. amplifier (which stray

harmonics may reach) are completely screened from the signal frequency circuits, no coupling between these can take place. In the present-day receiver the screening between the signal frequency circuits and the second detector is so thorough that interference due to the above cause is seldom experienced. The circuit of Fig. 22 is often used for I.F. filtration, however.

It is possible for trouble to be experienced owing to the production of harmonics by the first detector valve. If the receiver oscillator beats with an incoming carrier separated by one-half the intermediate frequency from the oscillator frequency, then the second harmonic of the resultant beat currents will produce the required intermediate frequency of the receiver. If the received

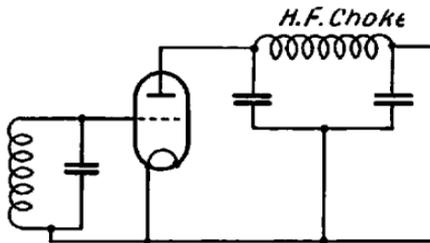


FIG. 22. CIRCUIT FOR ELIMINATING EFFECT OF I.F. HARMONICS

signal frequency is 1000 kc/s and the intermediate frequency is 100 kc/s, then if the interfering station has frequency of 1150 kc/s or 1050 kc/s, a beat frequency of 50 kc/s will be formed with the 1100 kc/s local oscillator. During rectification by the first detector harmonics are often produced, and the second harmonic of the 50 kc/s beat gives the required 100 kc/s to which the intermediate frequency amplifier is tuned. Interference will thus be produced. In a similar manner, a station separated from the oscillator frequency by one-third the intermediate frequency can cause interference due to the third harmonic (equal to three times the fundamental frequency) of the resultant beat frequency. Actually this does not occur very often, because the harmonics are usually much weaker than the fundamental frequency.

Reduction of interference due to this type of intermediate frequency harmonics can be effected in the same way as for beat interference, i.e. by using highly efficient circuits in the preselector part of the receiver. If the voltage induced by the interfering signal is reduced to a small value by selective circuits, the harmonics of the resultant beat frequency will be so weak as to be negligible so far as interference with the desired signal is concerned.

OSCILLATOR HARMONICS

A great deal of trouble can be caused by a poorly designed local oscillator that produces not only the desired high frequency current to be superimposed on the incoming signal to form the intermediate frequency, but generates in addition a number of harmonics. These harmonics, which are equal in frequency to the fundamental frequency of the oscillations multiplied by an integral number, beat with other signal frequencies and produce currents of the intermediate frequency.

Suppose that a desired incoming signal has a frequency of 250 kc/s, and that the local oscillator is set to 350 kc/s in order to form the 100 kc/s intermediate frequency. Harmonics of the local oscillations have the frequencies 700, 1050, 1400 kc/s, and so on, these being known as the second, third, and fourth harmonics respectively. The second harmonic (700 kc/s) will beat with frequencies of 600 kc/s and 800 kc/s to produce the required 100 kc/s intermediate frequency; while the third and fourth harmonics will beat with signals having frequencies of 950 kc/s and 1150 kc/s, and 1300 kc/s and 1500 kc/s respectively. These figures show that if harmonics are generated by the local oscillator the receiver is liable to a great deal of interference.

Oscillator harmonic interference was very common in the early days of the superheterodyne receiver. Many of the autodyne or self-heterodyne receivers described in the first chapter were characterized by considerable harmonic trouble. This is only to be expected when a single triode is used for the dual purpose of detection and generation of oscillations, for the nature of the function of the valve for rectification is such that distortion of the wave form is bound to occur due to the fact that one-half of the wave is not entirely suppressed. It is this distortion during detection that produces the harmonics of the oscillations if the latter are generated by the first detector valve.

It is essential to operate the valve entirely on the linear portion of its characteristic, for non-harmonic generation, and even when a separate valve is used as the oscillator, harmonics are often generated. Before the advent of the pentagrid valve, the use of a separate valve as the oscillator was, however, the only effective means of obtaining a completely satisfactory local generation of oscillations. In the pentagrid valve the two functions of oscillator and rectifier are so combined that the usual troubles encountered when other types of valves are used for these purposes are largely eliminated. The principles of the operation of the pentagrid valve are explained in a later chapter. At this stage it can be assumed that a separate oscillator valve is preferable to a single valve used as combined oscillator and first detector.

One of the best antidotes to the production of harmonics is sharply-tuned oscillator circuits. It follows that if a circuit is sharply tuned to a definite frequency it will offer a high impedance to the passage of a voltage 100 % off resonance such as the second harmonic. Here, then, is one means of reducing the interference due to oscillator harmonics. An effective circuit that has been frequently used is the tapped anode oscillator shown in Fig. 23. Here, the coupling between grid coil L_1 and anode coil L_2 is increased until oscillations are produced at a frequency determined by the resonance of the tuned circuit $L_2 C$. An alternative is the tapped grid oscillator arranged as in Fig. 24. The position of the grid tapping is adjusted to give a stable

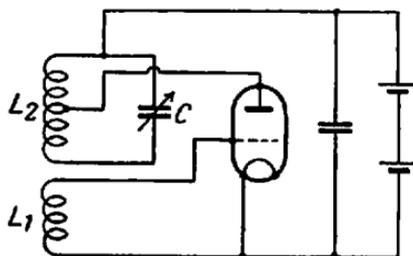


FIG. 23. TAPPED ANODE CIRCUIT OSCILLATOR

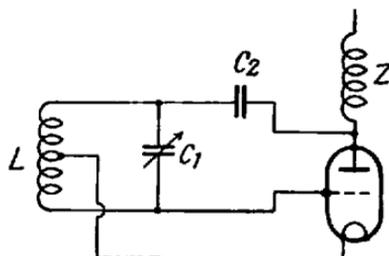


FIG. 24. TAPPED GRID CIRCUIT OSCILLATOR

generation of oscillations which will be at a frequency determined by the tune of circuit $L C_1$. A high frequency choke Z is connected in the anode circuit to confine the oscillations to the tuned grid circuit, while the condenser C_2 is for the purpose of preventing the H.T. voltage being applied to the grid, while at the same time allowing the high frequency currents to pass without hindrance.

In present-day practice the ordinary tuned anode oscillator is commonly used, two examples being given in the last chapter. If due attention is given to the design of the oscillator coils, and to the proper adjustment of the operating voltages of the oscillator it is found that little trouble need be experienced from harmonics. It should be noted that the introduction of high-efficiency iron-cored tuning coils has helped to diminish still further the introduction of oscillator harmonics into the first detector circuits.

An elaboration of the tuned circuit method of reducing oscillator harmonics is to insert an intermediate tuned circuit between the oscillator and the first detector. Although this is not usually required, the intermediate tuned circuit was used in a large number of American sets before the introduction of the high

frequency pentode enabled successful single-valve frequency-changer circuits to be designed. The arrangement most commonly employed is shown in Fig. 25. Here the oscillator valve *O* has its anode and grid circuits coupled to each other for generating oscillations by the usual feed-back method. The grid and anode coils, however, are not coupled directly, but through a third coil *L3*. This coil is tuned by condenser *C1*, and the adjustment of the latter determines the frequency of the oscillations generated. It will be seen that any feed-back from coil *L1* to coil *L2* has to pass through the intermediate circuit *L3 C1*, and this forms a highly selective oscillation generator circuit which may be coupled to the mixer valve *M* via the cathode coil *L4*. The oscillator

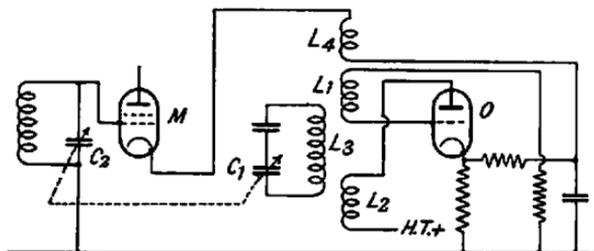


FIG. 25. ILLUSTRATING THE INTERMEDIATE CIRCUIT COUPLING BETWEEN OSCILLATOR ANODE AND GRID CIRCUITS

tuning condenser *C1* is ganged to the signal frequency circuit tuning condenser *C2* in the usual way.

SIDEBAND CUTTING

In a previous chapter was described the means whereby the superheterodyne receiver achieves such remarkable selectivity as compared with a straightforward high frequency amplifier. The important part of the receiver, so far as the selectivity is concerned, is the intermediate frequency amplifier where the frequency of the currents is low compared with the signal frequency, and where a given frequency difference between the desired and the interfering signals will represent a larger percentage difference than at the original signal frequency. It might appear, then, that as the tuning circuits are considerably more efficient at the lower intermediate frequency than they are at the signal frequency, it would be a comparatively simple problem to make the intermediate circuits as selective as desired, and to thus eliminate all vestige of interference from stations working on adjacent signal channels.

This, however, is not the case owing to the fact that a telephonic

signal does not consist of one single frequency, but of a whole gamut of frequencies from about 25 cycles to several thousand cycles per second, depending upon the quality of the signals transmitted. These frequencies are known as the *sidebands*, one sideband consisting of the complete range of audible frequencies transmitted. In a normal transmission system there will be one carrier and two sidebands, the latter being situated on either side of the carrier and usually consisting of frequencies up to 5000 cycles per second. This is depicted diagrammatically in Fig. 26. The carrier of 1000 kc/s frequency has the two sidebands, one on each side, so that the total range of frequencies to be received for faithful reproduction is from 995 kc/s to 1005 kc/s.

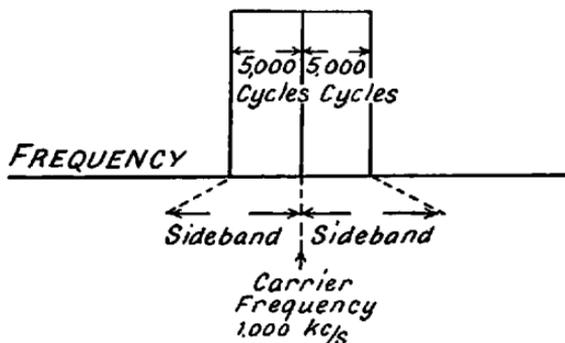


FIG. 26. GRAPHICAL REPRESENTATION OF THE COMPONENTS IN A RADIO TELEPHONIC SIGNAL

It follows from this brief consideration of the nature of a broadcast transmission that if the receiver circuits are very highly selective, the outer frequencies in the sidebands will not be able to pass through the receiver and so will be lost. This is known as *sideband cutting*, and was a prevalent fault in the earlier types of superheterodyne receiver.

The ideal condition of the receiving circuits for efficient reception of the carrier and sidebands is as seen in Fig. 27, where the carrier is equidistant between the two outer sideband frequencies, and the amplification of all the frequencies from 995 to 1005 is equal. The cut-off at the highest sideband frequency is complete.

Practical tuned circuit response curves are shown in Fig. 28. Curve 1 is for one tuned circuit, curve 2 for two tuned circuits, and curve 3 for three tuned circuits. As the number of tuned circuits is increased the receiver tends more and more to select the *carrier*, and not the sidebands containing the signal. Referring to the curves it will be seen that with three tuned circuits the

amplification of the highest frequency in the sideband (a 5000 cycle per second note) is only a small fraction of the amplification at the carrier wave frequency corresponding to zero frequency in

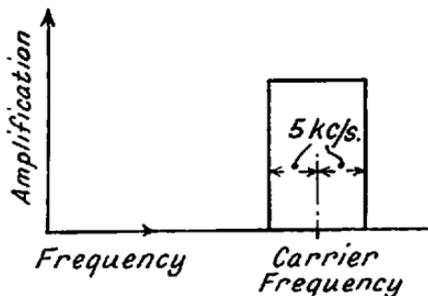


FIG. 27. THE IDEAL RECEIVER WOULD RESPOND IN THE MANNER INDICATED BY THIS CURVE

the telephony transmitted. It is for this reason that a number of sharply tuned circuits are not satisfactory for the faithful reception of broadcast transmissions.

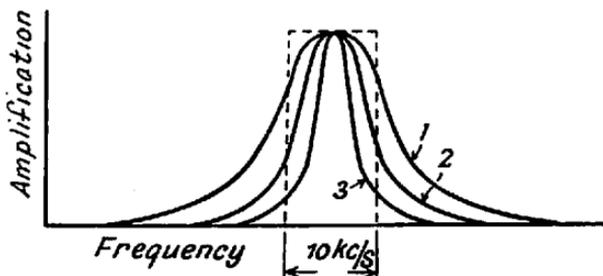


FIG. 28. ILLUSTRATING THE EFFECT OF TUNED CIRCUITS ON THE SIDEBANDS

Band-pass Filters. One method of overcoming this tendency of a sharply resonant circuit to cut off the higher frequencies in the sideband, is to design a circuit the response of which will more nearly approach that of the ideal as depicted in Fig. 27. Such a device is known as a *band-pass filter*, and examples are shown in Figs. 29 and 30.

In Fig. 29 the aerial inductance L_1 is coupled to L_2 which, with condenser C_1 and coil L_4 , form a complete tuned circuit. A second tuned circuit consists of coils L_3 and L_4 connected across condenser C_2 . It will be noted that there are two tuned

circuits coupled by a common inductance L_4 . The action of two tuned circuits coupled together in such a manner is somewhat complex, but it is sufficient, so far as at present concerns us, to

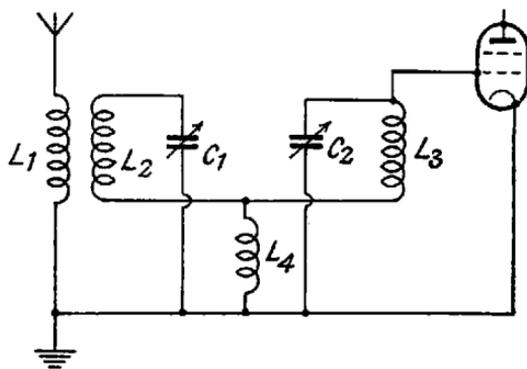


FIG. 29. CIRCUIT OF BAND-PASS FILTER EMPLOYING INDUCTIVE COUPLING

know that the resultant amplification-frequency curve is very flat-topped, and makes a reasonable approach to the ideal curve

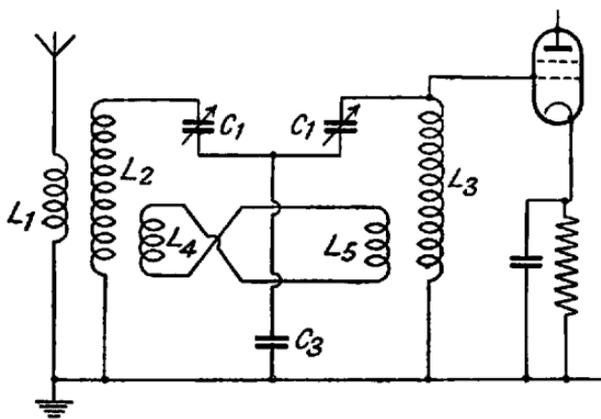


FIG. 30. BAND-PASS FILTER WITH COMBINED INDUCTIVE AND CAPACITATIVE COUPLING

shown in Fig. 27. The improvement in quality of reproduction as a result of the use of band-pass filters in place of ordinary tuned circuits is considerable.

Many modifications of the simple circuit shown in Fig. 29 can

be used. For example, a non-inductive condenser can replace the coil L_4 , and in addition to this another coupling condenser can be connected between the "top" ends of coils L_2 and L_3 . These two arrangements are known as *capacity coupled filters*. A further arrangement is seen in Fig. 30. In addition to the condenser coupling at C_3 there is the inductive coupling $L_4 L_5$ called the *linking circuit*. By combining the two types of coupling the band-pass filter of Fig. 30 gives very satisfactory results.

Tone Correction. Another method of overcoming the trouble due to sideband cutting is to employ a tone corrector in a post-detector circuit. The use of a tone corrector enables the pre-detector circuits to be made highly selective so as to eliminate the

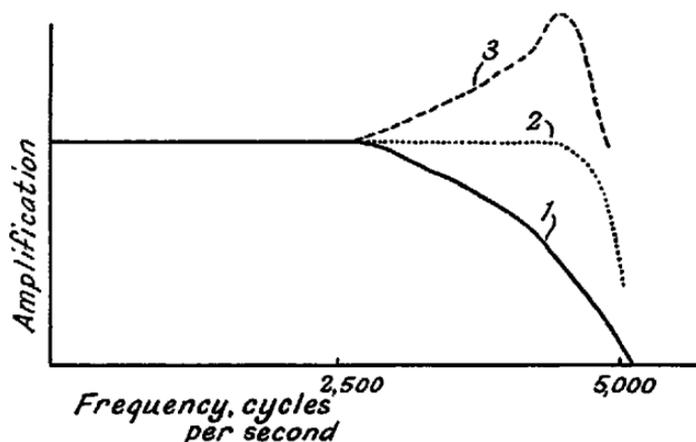


FIG. 31. CURVES ILLUSTRATING THE EFFECT OF TONE CORRECTION

various kinds of interference by unwanted transmitting stations. The sideband cutting that results from the use of selective circuits is then compensated by amplifying the high frequencies to a greater degree than the lower frequencies passed through the receiver without loss of amplification.

In Fig. 31 are shown a number of curves representing the amplification in, say, the output circuit of a detector valve of a receiver using tone correction. Curve 1 shows how the amplification of the higher frequencies diminishes from about 2500 to 5000, curve 2 represents the required correction, and curve 3 is the resultant overall amplification. It will be observed that as the amplification of the pre-detector stages diminishes the higher frequencies in the audio range, so the amplification in the low

frequency stage, by means of the tone corrector, increases the amplitude of these notes.

One arrangement commonly used to bring about this tone compensation is shown in Fig. 32. In the anode circuit of the second detector or first L.F. amplifier valve is connected a resistance R in series with the parallel circuit, consisting of choke Ch and condenser C . The corrector device illustrated is electrically in parallel with the valve V , and it can be shown that the effective amplification of this arrangement is influenced by the total impedance of the corrector circuit.

When a current corresponding to a received signal is passed into the anode circuit of valve V at low frequencies up to, say, 2,500 cycles per second, the impedance of condenser C is very great, so that practically all the current flows through Ch , the impedance of which is small. The net effect of this is that the anode circuit impedance consists almost entirely of the resistance R and the amplification will be uncorrected. As the frequency rises, however, the impedance of the resonant circuit Ch and C becomes greater until at about 5000 cycles per second it is a maximum. With the increasing impedance of the corrector circuit the effective amplification of the valve will rise, and so compensation is effected as seen in Fig. 31. After 5000 cycles per second is reached the impedance drops down again.

By suitable design of the tone corrector, automatic compensation for sideband cutting can thus be obtained. In practice, for example as described in Chapter VII in connection with the R.G.D. supersonic radio-gramophone, high quality reproduction is achieved by the combination of band-pass filters in the signal frequency and intermediate frequency stages, and tone correction in a post-detector circuit.

Variable selectivity is employed in some receivers to enable a better quality of reception to take place when the full sensitivity of the receiver is not in use.

For reception of a weak station, the selectivity is increased. The result of this is, as seen in Fig. 28, page 53, to reduce the amplitude of the higher frequencies in the sidebands and, at the same time, to cut out a certain amount of interference by other stations and background noise. Reception of the required distant station is thereby facilitated. For reception of a powerful station, the selectivity is reduced and the amplitude of the received higher sideband frequency is increased. This effects an improvement in quality.

The degree of variation in selectivity can be controlled in steps or gradually. One method of varying it in steps, that was used in 1931, is described on page 19. For altering the selectivity to any desired value between 7 and 12 kc/s, some manufacturers

make use of variable coupling between the I.F. transformers, which for this purpose are ganged together. As the coupling is varied, the amplitude/frequency curve of the I.F. circuits, of the type seen in Fig. 28, will vary between having a narrow width and being flat topped. See also page 69.

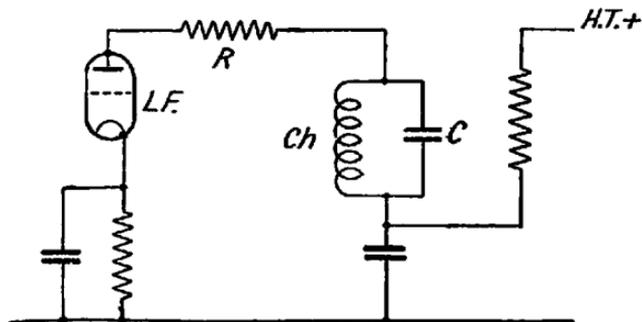


FIG. 32. THE COMMONLY-USED TONE CORRECTION CIRCUIT

BACKGROUND NOISE

Included under this heading is all the mush and hissing noise heard when a superheterodyne receiver is operating when no atmospheric or other signals are being received.

In the early superheterodyne receivers background noise was much more in evidence than it is to-day. The enormous strides made in valve manufacture have had a great deal to do with the improvement in this direction. A better understanding of the actual operation of the circuits and methods of obtaining purer oscillations have also helped in the reduction of background noise. This factor, nevertheless, still remains a drawback to the use of the superheterodyne receiver, and until it is eradicated entirely the signal amplification attainable by this receiver is limited.

A certain amount of the noise is due to an inherent property of the apparatus forming the circuits known as *thermal agitation*, and is caused by the spontaneous movement of the electrons in the circuits. A second disturbing factor is termed the *Schrott effect*. This is a result of the electronic discharge within a valve from the cathode impinging on the anode in such a way, that minute variations in voltages are set up in the anode circuit quite independently of those due to the signals or circuit dimensions. Both of the above effects take place in ordinary amplifiers, but they are particularly noticeable in superheterodyne receivers owing to the fact that there are generally more circuits and cathode-anode streams than in a straight receiver. Additional

background noise is caused by the minute voltages that are picked up by the stray wiring in the receiver. These voltages are amplified very powerfully and add their quota to the general noise level.

Another trouble, this one not being present in other types of receivers, is *oscillator hiss*. Nearly everyone has heard a quiet hissing sound when reaction is excessive in a straightforward design of receiver. This is known as oscillator hiss, and is due to the oscillations not being absolutely pure. Any noise due to the oscillator is superimposed on to the beat of the oscillator and incoming currents, and passes through the intermediate frequency amplifier, after which it is rectified and again amplified before reaching the loudspeaker.

It follows, then, that the hiss will be amplified to a degree depending to a great extent on the gain of the intermediate amplifier. The low frequency amplification is essential for satisfactory reproduction from the loudspeaker, but the amount of intermediate amplification employed varies according to the signal amplification desired by the listener. The remedy for oscillator hiss, therefore, lies in limiting the amplification of the intermediate frequency after everything has been done to make the local oscillations as pure as possible. This procedure is adopted in practice, and in order to compensate somewhat for the reduced intermediate frequency amplification, a signal frequency amplifier stage is usually employed between the aerial circuit and the first detector.

The greater the amplification before the signal currents reach the grid of the first detector valve, the less is the intermediate frequency amplification required for a given output intensity. Consequently the use of an efficient outside aerial is a decisive factor in the improvement of the signal to noise ratio. An indoor aerial can often be used, but as the "pick up" by it is so much less than that of a good outside aerial, more amplification in the receiver will be necessary for a given output, and, other things being equal, the louder will be the background noise.

Noise Suppressors. It is a common practice to fit a receiver with a device known as a *noise suppressor* or *sensitivity control*. This device consists of a resistance in the cathode lead of a variable μ I.F. amplifier valve with a switch across it, and is shown diagrammatically in Fig. 33. In the figure $R1$ is for the purpose of applying a minimum bias to the valve, and the noise suppressor resistance is $R2$. When the switch S is opened, making the noise suppressor operative, $R2$ is thrown into circuit and causes an additional grid bias to be applied to the valve. The value of $R2$ is arranged to be such that the extra bias it produces is sufficient to reduce the sensitivity of the receiver below the state in which noises are inclined to be troublesome.

LONG WAVELENGTH INTERFERENCE

One result of the anode circuit of the first detector being tuned to a long wavelength (corresponding to the intermediate frequency) is that any voltages that happen to be set up in that circuit by stations working at the same frequency, will be amplified powerfully and produce interference. Now, although the intermediate

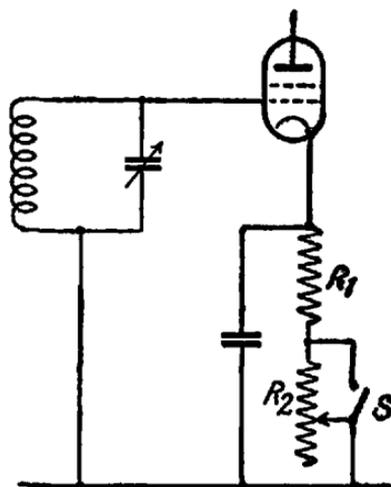


FIG. 33. MANUAL NOISE SUPPRESSOR ARRANGEMENT

frequency usually differs considerably from the desired frequency, and the interference signal must therefore be a long way off resonance, it is found in practice that quite an appreciable amount of interference is produced by this cause unless certain precautions are taken.

Fortunately long wavelength interference can be remedied by the same measures that are employed to overcome several other difficulties, i.e. effective preselection. The use of a band-pass filter in the first detector input circuit or a signal frequency amplifier, is usually sufficient to eliminate long wavelength interference. In receivers that do not include either of these, a wave trap tuned to the intermediate frequency is generally inserted in the aerial lead as shown in Fig. 34. If this rejector circuit is an efficient one, it will have such a high impedance at the frequency to which it is tuned (the intermediate frequency), that signals of this frequency will not be able to pass. Currents of other frequencies such as the desired signal frequency can go through the trap unhindered.

Direct pick-up by the intermediate frequency amplifier can easily take place owing to the coils and wiring acting as aerials. This type of interference is very seldom encountered these days,

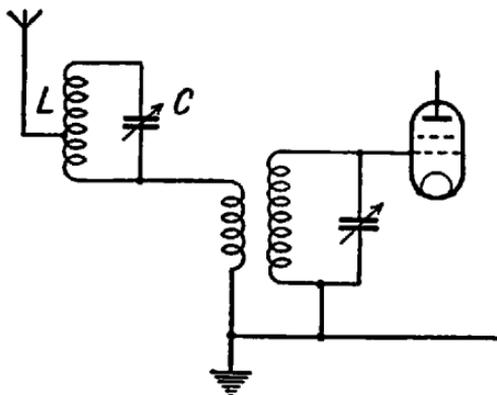


FIG. 34. THE REJECTOR CIRCUIT LC FORMS AN EFFECTIVE STOPPER FOR SIGNALS OF THE INTERMEDIATE FREQUENCY

as the screening, which is employed for efficiency in other respects, is a very effective antidote.

INSTABILITY

After having previously stated that one of the chief advantages of the superheterodyne receiver is its ability to amplify at a frequency that is low compared with the signal frequency without giving rise to instability troubles that are so apparent in a multi-stage high frequency amplifier, it may seem strange that instability should now be included among the difficulties associated with the operation of that receiver. It should be remembered, however, that many superheterodyne receivers have one stage of signal frequency amplification, and that the oscillator generates currents of a frequency usually higher than the signal frequency. Furthermore, the first detector valve has two high frequency currents impressed on its input circuit, the signal currents and the local oscillations. As previously explained, the first detector valve invariably produces harmonics during the process of rectification, so it follows that in the detector anode circuit there must also be many currents of a very high frequency notwithstanding that only the comparatively low intermediate frequency is selected by the output transformer for passing along to the amplifier.

Perhaps a brief consideration of the harmonic production by

the first detector will make this point clear. Suppose the incoming signal frequency is 1000 kc/s (corresponding to a wavelength of 300 metres), and the local oscillator is set to 1100 kc/s in order to beat with the incoming and form, after rectification, the intermediate frequency of 100 kc/s. In the anode circuit there will appear, disregarding the sidebands, the original frequencies of a 1000 kc/s and 1100 kc/s in addition to the beat frequency of 100 kc/s, and also harmonics of these at 2000 kc/s and 2200 kc/s. That the high frequency input to a detector valve is reproduced in the anode circuit, is proved by every receiver with a detector reaction control, for it is this high frequency component that is fed back to the input circuit again to augment the total output.

The problem of instability due to the feed-back of high frequency currents by the capacities of components, wiring, valves, etc., and also by stray electro-magnetic couplings, which is always accentuated when high frequency currents are being dealt with, is still present in the earlier stages of a superheterodyne receiver in exactly the same way as in a straight high frequency amplifier. Even the intermediate frequency amplifier cannot be overlooked in this respect, for currents oscillating at 100 kc/s (and intermediate frequencies up to 450 kc/s are common in America) can cause a great deal of trouble unless proper precautions are taken. Any tendency towards instability on the part of any portion of the intermediate frequency amplifier will throw out the tuning, and with it the overall amplification and selectivity.

Before the advent of screen-grid valves the instability of a superheterodyne receiver was made use of by designers who wanted to produce extremely sensitive receivers. In fact, the whole receiver was often worked so that it was on the verge of oscillation during reception of a distant station. The usual dodge to maintain stability was to apply to the grids of the intermediate frequency amplifiers a positive voltage by means of a potentiometer which was varied by the operator. The effect of a positive grid voltage was to cause grid current to flow, and this damped the circuit and maintained the receiver stable. Although this method of using the superheterodyne was quite satisfying to the distance-getting enthusiast in the days when good quality was unattainable as we now know it, and when there were not so many stations to choose from, it was superseded naturally by more scientific methods as the radio technique advanced, and listeners demanded receivers that were simple to operate and which gave good quality of reproduction.

Fortunately, the problem of stability is not a difficult one to solve in these days of high frequency pentodes. Valve inter-electrode capacity is not a major problem, and if the usual measures in design are taken to eliminate stray electrostatic and

electromagnetic coupling, no difficulties should be encountered. The preventives generally employed to eliminate undesired feedback, which result in unstable amplifiers, are careful screening and filtering by suitable chokes and condensers or resistances and condensers. As this is a matter which is essentially of interest only to designers, there is no object in examining it in great detail here.

The employment of a single-valve frequency changer usually entails a certain amount of risk of instability trouble due partly to the circuit arrangements, and also to the tendency of high-gain detector-oscillators to *squegger*, i.e. to set up a howl due to the charging and discharging of a condenser. Any instability due to the circuit used can generally be remedied by certain adjustments which reduce the magnification, while the liability to *squegger* is usually removed by making the time constant of the bias resistance and condenser small. When cathode injection of feed-back voltage is employed for the generation of oscillations, i.e. when the reaction coil is in the cathode circuit, it is essential that a very small number of turns in the cathode lead be employed so as to avoid the picking up of undesired oscillations by the reaction coil and the cathode wiring. The necessary voltage can be induced in the cathode coil by means of very tight coupling.

RADIATION

When the first detector is coupled to the aerial it is very difficult to avoid voltages of the frequency of the local oscillator being induced into the aerial circuit, and thus radiated into space in precisely the same manner as at a transmitting station, giving rise to interference in nearby receivers. It was mainly due to this trouble that the earlier types of superheterodyne receiver were almost invariably used in conjunction with a small frame aerial.

The remedy is to use a screen-grid signal frequency amplifier between the aerial and the first detector, for the stray local oscillations will not be able to pass over the minute internal capacity of the screen-grid valve. Although this is an effective antidote to radiation, there are a large number of receivers that only employ a small number of valves, and therefore cannot spare one valve for signal frequency amplification. If a single-valve frequency-changer is coupled to the aerial, the intensity of the radiation is largely governed by the grid-cathode capacity. It is important, therefore, to see that there is as little stray grid-cathode capacity in the circuit as possible.

It should be noted that no radiation takes place if electronic coupling between oscillator and first detector is employed, as in the case of the hexode and pentagrid valves outlined in Chapter V,

and the Cossor frequency-changer circuit described in this chapter under the heading, "The Optimum Heterodyne." Second channel suppression devices that make use of anti-phase coupling to the preselector circuits, also render great assistance in reducing radiation of the local oscillations by the aerial.

THE OPTIMUM HETERODYNE

The voltage of the local oscillations induced into the mixer circuit has a very considerable bearing on the working of the first detector. It can be shown, in fact, that the resultant signal intensity is dependent, up to a point, upon the product of the amplitudes of the incoming signal currents and the locally induced oscillations. The intensity of the local oscillations which operates the first detector at maximum efficiency is known as the *optimum heterodyne*, and it is essential for satisfactory working of a superheterodyne receiver that the optimum heterodyne should not be departed from very greatly. Unfortunately, the tendency of the oscillator circuits is to vary the voltage of the heterodyne as the frequency is altered.

For a proper understanding of the requirements for the optimum heterodyne, it is necessary to consider the effect of the locally induced oscillations on the operating point of the valve characteristic. A typical valve characteristic is shown in Fig. 35. It

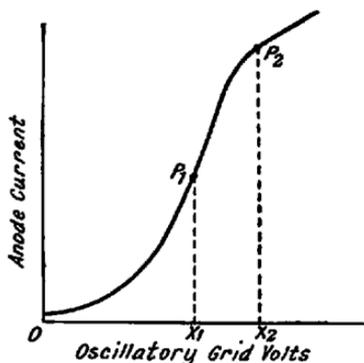


FIG. 35.
THE OPTIMUM HETERODYNE VOLTAGE IS THAT INDICATED BY OX_1 ALONG THE VALVE CHARACTERISTIC

is seen that for maximum amplification of a signal the operating voltages applied to the valve should be so adjusted that the signal voltages are effective at the point P_1 , for at this part of the characteristic the slope is steepest and a given variation in grid voltage will result in a maximum alteration in anode current. The optimum heterodyne is, therefore, the local oscillation intensity that is applied to the first detector valve to cause the operating point on the characteristic, so far as the incoming signal is concerned, to be situated at P .

The curves of the oscillator and of the incoming signal currents were shown in Fig. 14, and are reproduced in Fig. 36. For best results the voltage V due to the local oscillations must be equal to OX_1 , Fig. 35. The conditions for optimum heterodyne will then

be fulfilled, because the resulting voltage variations due to the signals will cause the grid voltage to fluctuate along the steepest part of the valve characteristic. It should be noted that if the heterodyne voltage is too strong, the operating point will move upwards, and may possibly reach the point *P2*, Fig. 35. If this were to happen the resulting amplification would be much less, and would obviously be non-linear. Grid current would flow and damp the input circuit, producing a reduction in selectivity and causing cross modulation.

It is thus seen that if a superheterodyne receiver is to give satisfactory results, it is important that the voltage induced by the local oscillator into the mixing circuit, should be substantially

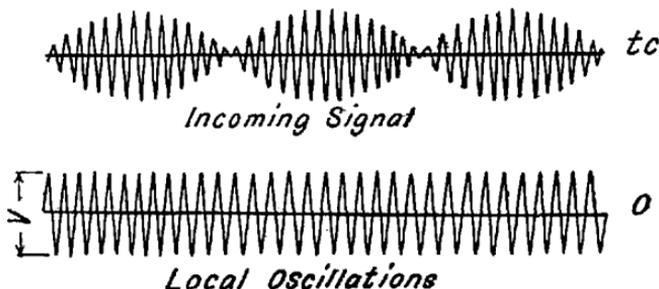


FIG. 36. FOR OPTIMUM HETERODYNE, THE VOLTAGE V SHOULD BE EQUAL TO OX_1 OF FIG. 35

constant. Most oscillators, however, work more efficiently at the higher frequencies than at the lower ones. If the local oscillator is adjusted for optimum heterodyne at a high frequency, it is often found that at the lower frequencies the induced voltage in the first detector grid circuit is so small that the detection of the beat frequency is ineffective. On the other hand, should the oscillator be adjusted to produce the optimum heterodyne at one of the lower frequencies, it is very probable that the first detector will be overloaded during reception of the higher frequencies. The operating point in the latter instance will probably have been moved up the characteristic to point *P2*, Fig. 35, and the undesirable effects mentioned above will take place.

One method of smoothing out the voltage variations of the oscillator is to connect a grid leak and condenser to the circuit as shown in Fig. 37. With this arrangement, a flow of oscillator grid current due to an excessive oscillation voltage will produce a voltage drop down the grid leak and thus cause an increase in effective negative grid bias. This reduces the anode current, and consequently the feed-back, of oscillatory voltage.

The simple expedient of joining a resistance across the cathode injection coil of a single-valve frequency-changer is found to be quite effective in diminishing the more violent deviations from the optimum heterodyne. This resistance is generally of the order of 400 ohms.

Since the reactance of a coupling coil varies with the frequency, a greater voltage will be applied by it at the higher frequencies than at the lower ones. This disability can be overcome by using some kind of coupling which will counteract this tendency, such as a coupling system consisting of capacity only, or mixed inductive and capacitive elements. Capacitative coupling is used in a number of receivers, the coupling between first detector and oscillator valves being effected by a condenser in their common cathode lead. Some receivers employ resistance coupling for this purpose.

Automatic grid bias is a good antidote for excessive oscillation voltage, and is employed in a large number of receivers. As the intensity of the generated oscillations increases the anode current becomes greater correspondingly and, since the bias applied to the valve bears a direct relation to the current flow along the bias resistance, the grid bias will also increase. The rise in negative bias at the grid with any increase in anode current flow thus serves the very useful purpose of keeping a check on the voltage of the oscillations generated.

A method of overcoming trouble due to a fluctuating oscillator voltage, developed by the manufacturers of the "Westector," consists in using a recently introduced type of Westinghouse metal rectifier, known as Type WX, as the first detector. If this is done, an optimum heterodyne is not required, for the characteristic of the Westector Type WX is linear for applied voltages greater than three volts. All that is necessary for satisfactory operation of the first detector stage is a heterodyne voltage several times higher than that provided by the H.F. amplifier. A signal frequency amplifier is needed when using the Westector as first detector, in order to avoid radiation of the local oscillations and to provide the necessary degree of preselection.

A circuit for using the metal rectifier as first detector is shown

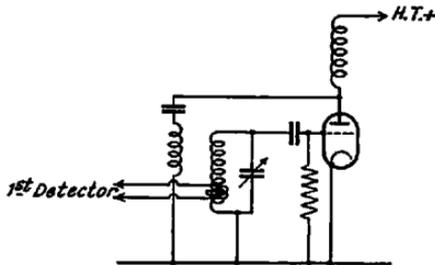


FIG. 37. THE GRID CONDENSER AND LEAK IN THIS ARRANGEMENT HAVE THE EFFECT OF SMOOTHING OUT OSCILLATION FLUCTUATIONS

in Fig. 38. Valve V_1 is a normal screen-grid amplifier which supplies signal frequency currents to the circuit $L_1 C_1$ tuned to them. The oscillator is V_2 , the tuned anode circuit of which is connected over the load resistance R to the Westector W . The rectifier is thus fed with the incoming signals from $L_1 C_1$, and the local oscillations from $L_2 C_2$. These two oscillatory currents are combined in the circuit and the beats, after rectification by W , impress an intermediate frequency voltage across R . This voltage is selected by the primary L_4 of the intermediate frequency

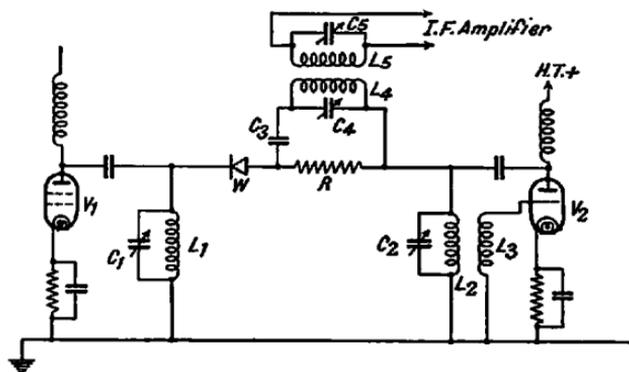


FIG. 38. IN THIS ARRANGEMENT THE WESTECTOR IS USED AS FIRST DETECTOR

transformer and passed to the I.F. amplifier via the secondary winding L_5 . The reservoir capacity for the effective operation of the Westector consists of condensers C_3 and C_4 in series.

Electronic Mixing. When a hexode or pentagrid is used as frequency changer, the voltage generated by the oscillator is not so critical of adjustment for the efficient working of the system as when other types of valve are used for this purpose, owing to the electronic coupling that is employed for mixing the local and the incoming oscillations, as described in Chapter V. Another method of employing electronic coupling is used by Messrs. A. C. Cossor, Ltd., in their "635 Mains Superhet," in which a separate triode oscillator feeds the heterodyne voltage to the suppressor grid of the first detector valve working as an anode bend detector. This method of combining the incoming with the local oscillations overcomes the difficulty of generating the optimum heterodyne, for the oscillator voltage is not impressed upon the first detector control grid, and so will not affect the working point of the grid volts/anode current characteristic. It possesses the additional

advantages that radiation does not take place, and there is no interaction between the preselector and the oscillator circuits.

A simplified version of the circuit in which electronic mixing takes place is shown in Fig. 39. The input circuit $L_1 C_1$ tuned to the incoming signal is connected to the control grid and cathode of the anode bend detector D . Valve O is adjusted to generate oscillations by means of feed-back between coils $L_3 L_2$, the grid circuit $L_3 C_2$ being tuned to the oscillation frequency. Voltage from the tuned anode circuit of the oscillator is applied by a

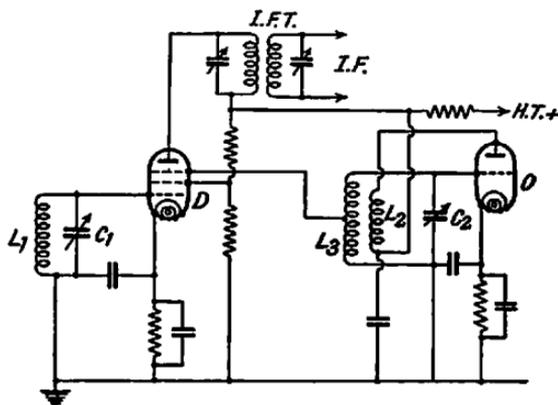


FIG. 39. A COSSOR TWO-VALVE ARRANGEMENT IN WHICH ELECTRONIC MIXING TAKES PLACE

direct conductive connection to the suppressor grid of the first detector. This voltage is adjustable by a tapping on the oscillator grid coil, or an impedance may be joined in the connection between the oscillator grid and the detector suppressor grid.

In this arrangement the local oscillations are superimposed on the incoming signal currents through the common electronic stream. The high frequency voltage impressed upon the suppressor grid by the oscillator modulates the cathode-anode stream accordingly, and this modulation, added to the effect of the signal voltages applied to the control grid, produces beat frequency currents which are rectified by the anode bend method, selected by the primary circuit of the intermediate frequency transformer and passed through to the amplifier stages.

OSCILLATOR DRIFT

In the various notes on the formation of the intermediate frequency that have so far appeared in this book, it has been assumed that the oscillator frequency was sufficiently stable to

apply to the mixer circuit the exact frequency required to produce the intermediate frequency. It is, however, not at all an easy matter to construct an oscillator that will maintain a constant of oscillatory frequency voltage. On the medium and long wavelength bands a slight drift from the required oscillation frequency will not cause any serious consequences, but on the short wavelengths very poor reception will be obtained unless special steps are taken to make the constancy of frequency much more perfect.

The effect of oscillator drift, as this phenomenon is called, can be best explained by the consideration of actual cases. The local oscillator is usually capable of maintaining a degree of constancy of 1 in 1000. This means that if it is desired to generate a frequency of 1000 kc/s, the oscillator will not deviate from this frequency by more than 1 kc. under normal operating conditions. Now suppose that reception is desired with the oscillator at 30 metres, 450 metres and 1500 metres, corresponding to frequencies of 10,000 kc/s, 700 kc/s and 200 kc/s, respectively. If the oscillator frequency drifts the full amount allowable, i.e. one part in one thousand, the corresponding deviations from the desired frequency will be 10 kc/s, 0.7 kc/s and 0.2 kc/s, respectively. This drift on the long waves, (0.2 kc/s. or 200 cycles per second) will not be perceptible in the usual broadcast reception, and neither will the drift on the medium waveband, namely, 0.7 kc/s or 700 cycles per second. During reception of the short wavelength station, however, when the oscillator was set to 10,000 kc/s, the drift is as much as 10 kc/s.

The significance of this can be appreciated by a perusal of the curves shown in Fig. 40. Suppose that the oscillator is required to be set at 10,000 kc/s for reception of a signal on 10,100 kc/s, and that the intermediate frequency is 100 kc/s. If the intermediate frequency amplifier valve is coupled by the normal type of I.F. transformer with a 9 kc/s band-pass characteristic, the frequency-amplification curve of the I.F. transformers will be as shown at *A*, Fig. 40. If the local oscillation frequency drifts by one part in a thousand, the resultant intermediate frequency will be altered correspondingly, i.e. by the actual amount of the drift. In the present case, the oscillator drift is 10 kc/s, and the I.F. will move to either 90 kc/s or 110 kc/s. In both instances, the drift is sufficient to move the actual intermediate frequency off the 9 kc/s response frequency band of the I.F. transformer, and reception will not be possible. It is thus seen that the inconstancy of a local oscillator is liable to cause a very serious reduction in the efficiency of the receiver during reception of short waves, and that the shorter the wavelength being received the more difficult will it be to maintain the resultant intermediate

frequency within the tuning range of the intermediate frequency transformer.

An obvious step to take is to make the intermediate frequency circuits into a band-pass filter with a very wide frequency range. For example, in Fig. 40, if the resonance band of the circuits was broadened to include all the three curves *A*, *B* and *C*, as shown in the broken line, it would pass the resultant intermediate

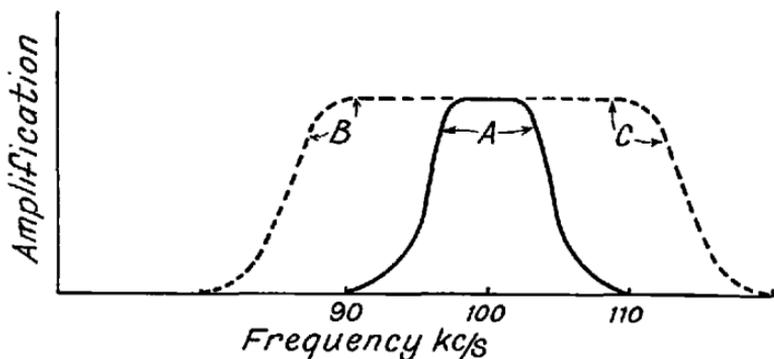


FIG. 40. CURVE *BC* REDUCES EFFECT OF OSCILLATOR DRIFT

frequency notwithstanding the oscillator drift of one part in a thousand. To employ a band-pass filter with such a wide range results in a loss of signal strength owing to the reduced efficiency of the circuits, but this disadvantage is preferable to a considerably more serious loss of signal intensity which would be brought about by the inconstancy of the oscillator frequency.

It might be mentioned here that the frequency of oscillations generated by a heptode valve is liable to some alteration when the grid bias applied to the signal grid is varied over wide values.

VARIABLE SELECTIVITY

It has been shown that highly selective circuits bring about the undesired effect of diminished intensity of the higher audio frequencies, and that in a receiver designed for a high degree of fidelity in reproduction, some measures have to be taken to compensate for this type of distortion. In general, however, it is found that receivers in which sideband cutting is compensated by subsequent tone correction do not give such satisfactory tonal reproduction as receivers in which less selective high frequency circuits are employed, with consequently less tone correction. The degree of selectivity required for reception is dependent upon the closeness of the transmission channels and the number and

power of transmission stations in a given area, and it is outside the power of the receiver designer to alter this factor. On the other hand, signals are frequently received at such strength that no interference would be experienced from stations working on adjacent channels even though the high frequency circuits be made much less selective and thus enabled to pass a larger range of the sideband frequencies.

The ideal arrangement is clearly one in which the receiver is made just selective enough to receive the desired signals clear from interference. Selectivity greater than this will entail unnecessary diminution of the sidebands, while less selectivity will cause the interfering stations to be received with the wanted one. For example, if it is found that for reception of the local station, sideband frequencies up to 12 kc/s can be passed by the high and intermediate frequency stages, there is no object in having the circuits so selective that sideband frequencies up to only 4.5 kc/s are passed. If, however, during reception of a distant station, interference is experienced when the receiver is adjusted to pass up to 4.5 kc/s, then the circuits should be made even more selective.

In considering this variation in selectivity it should be borne in mind that unless the arrangement is such that the sides of the selectivity curve are moved symmetrically, the benefit of the device will largely be lost. This will be apparent from a glance at Figs. 27 and 28. The ideal variable selectivity device causes the sides of the receiver selectivity characteristic to move as a whole parallel with the ideal 5 kc/s characteristic. This means that the selectivity characteristic should contract for maximum selectivity, and expand for greatest fidelity, while retaining its precise shape. If this does not take place, but instead the sides of the curve are merely made more sloping, then the undesirable effects illustrated by the curves in Fig. 28 are brought about when the selectivity is reduced, i.e. the higher musical frequencies are not received at the same strength as the lower ones.

On page 19 is shown a diagram (Fig. 11) of a circuit that was used in 1931 for obtaining some degree of selectivity control. In effect, the added resistance flattened the tuning, and gave the receiver a selectivity characteristic with sloping sides. This was undesirable for reasons given above.

The signal frequency stages of the receiver are not readily adaptable for varying the selectivity in a satisfactory manner owing to the necessity to tune them over a comparatively wide band of frequencies.

An arrangement that is workable at a carrier frequency of say 1500 kc/s would not be at all satisfactory during reception of a 500 kc/s signal.

For producing a variation in selectivity, the most adaptable

part of a superheterodyne receiver is an intermediate frequency amplifier stage, for this is tuned to one frequency only and there are thus no varying factors to be considered as the receiving waveband is altered. The intermediate frequency transformer offers a suitable means for affecting the variation in selectivity, and most receivers employing this feature utilize a device that alters the coupling between the primary and secondary windings. This

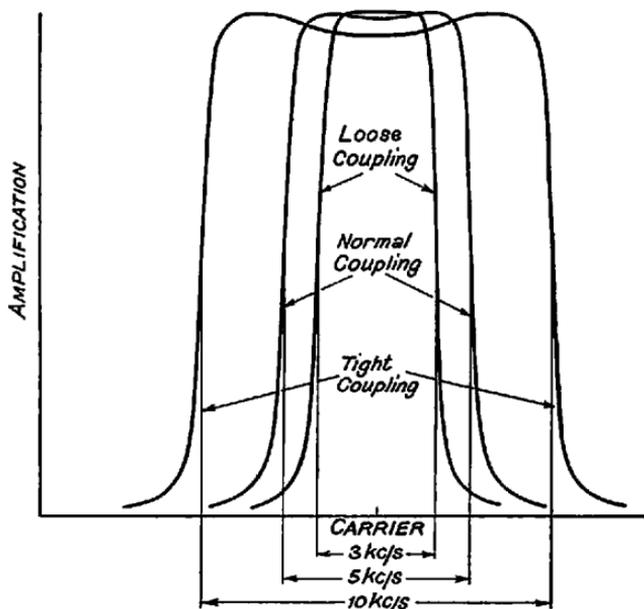


FIG. 41. VARIABLE SELECTIVITY CURVES

variation in coupling is brought about by altering manually the spatial relation of the windings, or by keeping this fixed but having an additional small coil added to each winding. The two added coils are movable relative to each other so that a variation in mutual inductance is effected, resulting in an expansion or contraction of the width of the selectivity curve. As the mutual inductance is increased by either of these methods, the curve is expanded symmetrically as desired. In Fig. 41 is shown the characteristic of an intermediate frequency transformer with varying mutual inductance. The inner curve *a* is in respect of the most selective condition of the transformer, and it is seen that the side-band frequencies above 3000 are greatly attenuated. As the selectivity curve is expanded, the middle curve is produced,

resulting in frequencies up to 5000 being receivable. In the condition of minimum selectivity and greatest fidelity, the outer curve sideband frequencies up to 10,000 are passed by the transformer.

THE "ALL-WAVE" SUPERHETERODYNE

A receiver that is capable of tuning over some hert wavebands in addition to the medium and long wavebands, is given the ambitious name of "all-wave" receiver. The actual circuit arrangement and method of functioning of an "all-wave" receiver is usually not essentially different from the normal medium and long wavelength receiver. This is evident from a perusal of the description and circuit diagram of the all-wave receiver given in Chapter VII. There are, nevertheless, some important considerations that enter into the design of an all-wave receiver, and these will be discussed in this section.

The component that is the most critical in the operation of the short wave section of a receiver is the oscillator valve. Unless this generates stable oscillations the difficulties outlined under the section headed "Oscillator Drift" will be experienced. Furthermore, the oscillation voltage produced must be above a certain minimum value, otherwise the mixing process cannot be carried out satisfactorily. This means that the oscillator valve must have a high slope. Another requirement if a single valve frequency changer is used is that there shall be very small inter-electrode capacity between the oscillator section and the mixer section, so as to avoid interaction between the oscillator and signal frequency circuits. This will be readily appreciated when it is recalled that on the short waves the percentage difference between the two frequencies is very small, and the tendency to interact, or "pull," is correspondingly increased. The impedance of the inter-electrode capacity is greatly reduced at very high frequencies, and this again will increase the tendency towards interaction. It is thus seen that the selection of the oscillator valve or frequency changer calls for careful consideration.

Not only is the percentage difference between oscillator and signal frequencies reduced during reception of short waves, but the percentage difference between the signal frequency and second channel frequency is also reduced. The unfortunate result of this is that it becomes increasingly difficult to suppress second channel reception on the short waves. One way to diminish the difficulty is to employ a higher intermediate frequency, since the second channel frequency is separated from the desired signal frequency by twice the intermediate frequency. This is done by most manufacturers, and an intermediate frequency of approximately 450 kc/s is commonly used.

For reception on short waves, very small values of inductance are needed in the tuning coils. Consequently, the inductance of the wires connecting the circuit components may easily represent a large part of the total inductance unless they are kept extremely short. In these circumstances, the actual tuning coil may be so small that the coupling is insufficient to enable the receiver to work efficiently. At very high frequencies there is also a great risk of stray coupling existing between the leads and adjacent circuits, and the operation of the entire receiver being thereby thrown out. A similar difficulty is the existence of stray capacities, either between the wiring itself or across switch contacts, etc., which, owing to the low impedance offered to the very high frequencies, may cause serious loss due to H.F. short circuits and interaction. It is apparent, therefore, that the designer of an all-wave receiver has to be much more careful in regard to screening and chassis assembly than the designer of a receiver for operation on the medium and long waves only.

CAR RADIO

The superheterodyne principle finds a ready application for purposes of radio reception on motor-cars. This is due to the possibility of being able to design a superheterodyne receiver to give a high degree of amplification while its physical dimensions are kept very small. A high gain is necessary in a car radio receiver because the aerial used in conjunction with it is very small and inefficient. The space available for the receiver is obviously very limited in all but exceptional instances.

The general conditions under which car radio reception takes place are, quite apart from the considerations mentioned above, very unsatisfactory. The ignition system of the engine constitutes a powerful local transmitter that radiates a wide band of frequencies and therefore cannot be tuned out by the usual radio tuning devices. This local transmission is complicated by the making and breaking of various contacts which sends the interfering waves over the whole wiring system of the car. Means have to be provided, therefore, for effectively screening the receiver from the interference set up by the engine. In most cases this can be carried out by fitting suppressor units, consisting of resistances and/or condensers, to the sparking plugs in series with the individual leads, and to the H.T. distributor and to the dynamo.

A very efficient system of automatic volume control is required, owing to the greatly fluctuating input to the receiver that is brought about by the movement of the vehicle.

Various types of aerial are employed for car radio receivers. The most popular is the roof aerial, consisting of about one square yard of cooper gauze or galvanized iron wire netting

fitted behind the head lining. In many instances cars are fitted with aërials before leaving the factory. Other kinds of aerial are employed, however, which prove to be quite satisfactory. There is, for example, the running board aerial consisting of two metal plates situated under each running board and connected together by a tie rod; and the "V" aerial which is fitted between the rear axle and an intermediary part of the chassis. The G.E.C. car receiver is described in Chapter VII.

AUTOMATIC TUNING CORRECTION

The use of fixed tuning for the intermediate frequency amplifier has one disadvantage: when the voltage fed to the intermediate transformer is slightly out of tune with the resonance frequency of the latter, distortion is produced due to the unequal amplification of the sideband spectrum. When a signal is tuned-in *exactly*, all is well, for then the difference between the signal frequency and the oscillator frequency is equal to the intermediate frequency. If slight mistuning takes place, however, the signal will still be received but the difference between oscillator and signal frequency as tuned in will not be that of the intermediate frequency. For example, suppose a station working on 1000 kc/s is being received, and that the intermediate frequency is 100 kc/s, requiring an oscillator frequency of 1100 kc/s. Due to the alignment of the circuits, the difference in tuning between oscillator and signal circuits is always 100 kc/s. When slight mistuning takes place, say to 1004 kc/s in the signal frequency circuit (oscillator at 1104 kc/s) the actual difference in receiver tuning is still 100 kc/s, but owing to the signal setting up a voltage in the circuits at 1000 kc/s, notwithstanding the mistuning of the signal frequency circuits to the extent of 4 kc/s, the *real* intermediate frequency (equal to the oscillator frequency minus the actual signal frequency) is $1104 - 1000 = 104$ kc/s. This means that the intermediate frequency passed by the frequency changer valve is 4 kc/s out of tune with the intermediate frequency circuits and distortion in the reproduced signal will result.

It would appear, therefore, that when an unskilled operator—such as the average listener who handles a superheterodyne receiver—tunes in there is every possibility of his not receiving signals with the fidelity that the receiver is capable of reproducing. A device that automatically corrects for any slight mistuning that may take place in practice is likely to bring much greater satisfaction to the listener than if he has to depend entirely on his own skill at tuning. Messrs. Murphy Radio, Ltd., have successfully tackled this question of automatic tuning correction and have put on the market a series of receivers in which is incorporated a device that automatically corrects mistuning.

These receivers are known as the "28" series. Details of the working of the corrector are given by E. J. Power, Chief Engineer of Murphy Radio, Ltd., in the *Murphy News*, dated 24th August, 1935, and the writer is indebted to the editor of that journal for permission to reproduce Fig. 42 and to base this description on information contained in the article referred to.

The principle underlying the action of Murphy Radio's automatic tuning correction is that if two circuits are coupled to the I.F. amplifier, each slightly off resonance on opposite sides

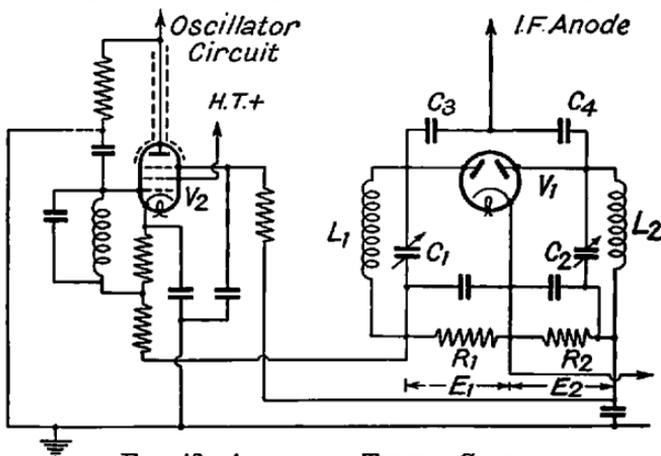


FIG. 42. AUTOMATIC TUNING CIRCUIT

of the I.F. resonance frequency, and the voltages induced in these circuits are arranged to be in opposition, then the resultant voltage (equal to the algebraic sum of the individual voltages) will bear a definite relation to the degree of mistuning. This voltage is then applied to a pentode valve acting as a reactance across the tuned oscillator circuit, in such a manner that the oscillator frequency is varied to balance out the mistuning of the receiver.

In Fig. 42 is shown the actual circuit arrangements employed in the series of receivers already mentioned. A lead from the intermediate frequency amplifier anode is taken to small coupling condensers C_3 , C_4 . This enables voltages of intermediate frequency to be applied to the two tuned circuits $L_1 C_1$ and $L_2 C_2$, which are resonant respectively slightly above and slightly below the correct intermediate frequency. Double diode valve V_1 rectifies these two voltages and the D.C. component appearing across the load resistances R_1 and R_2 , represented in the diagram as E_1 and E_2 , are in opposition. The resultant voltage is applied

to the suppressor grid of V_2 (an H.F. pentode), which is connected in parallel to the tuned oscillator circuit. The arrangement of V_2 is such that the impedance between its anode and cathode is reactive, and as the voltage applied to its suppressor grid varies according to the degree of mistuning so also does the slope of the valve and consequently the reactance it represents. As this reactance is joined across the oscillator circuit, the frequency to which the latter is tuned varies to a degree depending upon the alteration of the reactance of V_2 , i.e. according to the original degree of mistuning effected by the operator.

In this way tuning compensation is brought about and the difference between signal and oscillator frequency more exactly equals the intermediate frequency. In the case of the numerical example quoted above where the signal frequency circuits were tuned to 1004 kc/s while receiving a signal on 1000 kc/s, the oscillator frequency would be altered by this automatic device from its correct value of 1104 kc/s to 1100 kc/s. Thus, although the signal frequency circuits still remain out of tune as adjusted by the operator, the tracking between oscillator and signal frequency circuits is modified to bring about a corresponding compensation.

In practice, this device does not come into operation until after the tuning knob is released. It is operated after a time delay by a switch that is frictionally coupled to the tuning spindle.

CHAPTER V

SINGLE-VALVE FREQUENCY CHANGERS

IN a superheterodyne receiver the part in which the incoming frequency is changed to the intermediate frequency is known as the frequency changer. It has already been mentioned that this process involves the generation of a local oscillation, the mixing of this oscillation with the incoming signal frequency, rectification of the combined frequency, and selection of the intermediate frequency. Of these four separate functions two are carried out by the circuit arrangements (mixing and intermediate frequency selection) and two by the valve (generation and detection). It is for the latter reason that when one valve is used for the two purposes, it is also called the *detector-oscillator*.

The idea of using only one valve for the combined duties of local oscillation generator and first detector has intrigued the minds of inventors and designers from the very earliest days of the superheterodyne receiver. In Chapter II are described circuits devised by Armstrong and Houck with this object in view in the early 1920's. The reason such intensive efforts have been made to combine the two operations in one valve is that the local generator does not take an active part in the actual amplification of the receiver. It has always been the Cinderella of the superheterodyne.

Until comparatively recently, single-valve frequency changers have not been very successful. They have been used in various types of receivers that have made an appeal on account of their moderate cost, but high-class superheterodyne receivers have used a separate valve for the heterodyne. Even when a separate oscillator valve is used, the *conversion gain*—i.e. the ratio of the I.F. output voltage to the signal frequency input voltage—of the detector valve is not so great as when the same valve is employed as a straight amplifier. The variable μ H.F. pentode has been the most successful detector-oscillator until the advent of the new hexode and pentagrid valves, although a special four-electrode valve has been used by Continental manufacturers for some years.

There are many causes that militate against the satisfactory operation of a triode or ordinary screen-grid valve as combined detector-oscillator. One is that excessive harmonic generation invariably takes place, even when precautions are taken to avoid trouble due to this defect. Harmonics are produced by the

distortion of the oscillator wave form, due to the amplitude of the oscillations attaining such a value that the voltage on the grid exceeds the maximum permissible for linear operation. This causes the wave form to be flat topped and not a pure sine wave. The more flat topped the wave form is, the greater will be the harmonic content. Even when a valve is working solely as an oscillator, it is difficult to avoid the generation of harmonics. When, however, detection is also required of the valve, harmonic generation is almost a certainty. This is because when a valve is used for detection, it is operated on a bend of its characteristic, whereas for oscillation generation it should be operated on a linear portion of its characteristic. These two requirements are thus conflicting, and to a great extent explain why the ordinary single-valve frequency changers have not been adopted universally.

It follows that a single-valve frequency changer cannot rectify the combined high frequency currents so efficiently as a valve that has only this one function to carry out.

Another drawback to the employment of single-valve frequency changers is that arrangements cannot be devised, except when use is made of the special valves described later in this chapter, to avoid interaction between the oscillator and detector circuits. There is bound to be a certain amount of reaction between these two circuits, owing to one part of the valve connections being common to both, and this creates difficulties in the tuning of the two circuits. When the tuning of one circuit is altered, not only is the tuning of the other circuit also affected, but the degree of coupling must also vary in many cases. Furthermore, if the mixer valve is coupled to the aerial without the interposition of a screen-grid signal frequency amplifier, there is likely to be a certain amount of radiation and consequent disturbance to nearby receivers. The degree of these interaction and radiation troubles depends, of course, on the circuit arrangements and can be kept low with modern designs.

In this chapter are outlined some of the more serious and interesting attempts to produce a single-valve frequency changer. Most of the arrangements described are of comparatively recent development, or else have actually been in use until fairly recent years. The early types of detector-oscillator circuits, using triode valves, have already been mentioned in the second chapter. Such circuits as the Houck harmonic frequency changer and the "Tropodyne" are now only of academic interest. The nature of their operation is such that spurious harmonics are bound to be very strong and considerable interference is produced. Trouble due to interaction between the circuits is also experienced. Although these circuits were used to some extent in the days

when there were only a few transmitting stations, they are totally useless under present conditions.

Conversion Conductance. In connection with frequency changers it has been found desirable to use a term that will express the efficiency of the valve in a similar way to that implied by the

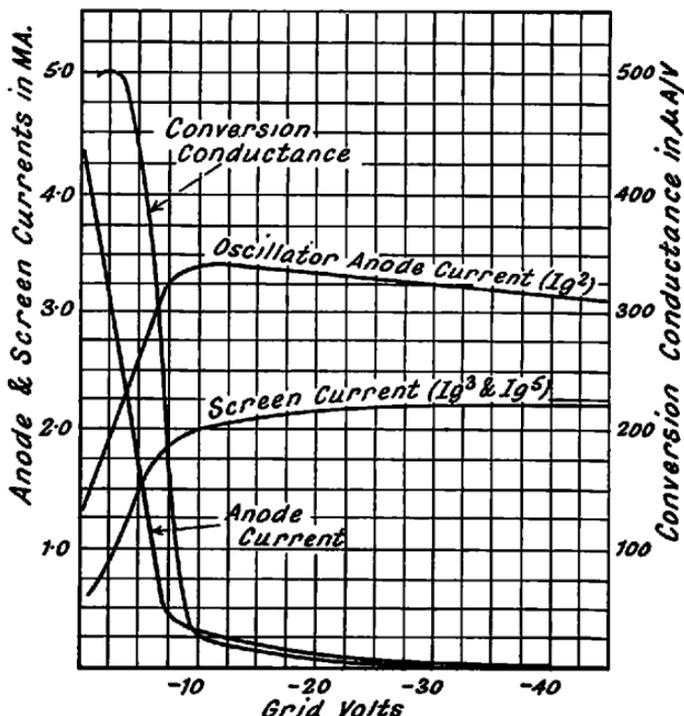


FIG. 43. CHARACTERISTIC CURVES OF MARCONI HEPTODE MX40, SHOWING CONVERSION CONDUCTANCE

mutual conductance of an amplifier valve. This term is the *conversion conductance*, which is the ratio of the intermediate frequency current in microamperes in the anode circuit to the signal voltage input.

A conversion conductance curve is seen in Fig. 43. For completeness, the other relevant curves of the valve are also shown. It will be noted that the conversion conductance is controlled by the signal control grid (the valve being a heptode). When this grid is at 3 volts negative, the conversion conductance is 500 microamperes per volt, whereas when the control grid is at 30 volts

negative the conversion conductance falls to only 2 microamperes per volt. It is quite apparent that this type of valve is suitable for automatic volume control purposes.

The Bigrid Valve Circuit. This circuit has been used fairly extensively. It makes use of the bigrid valve, which has two grids between anode and cathode. The circuit diagram is shown in Fig. 44, where the input circuit $L_1 C_1$ is tuned to the incoming signal frequency, and $L_2 C_2$ to the heterodyne frequency generated by coupling L_2 to the anode circuit coil L_3 . The input and oscillation circuits are connected to separate grids, so that they do not possess any circuit coupling element in common.

Unfortunately, it is found that by adjusting the operating voltages so that rectification takes place between the cathode,

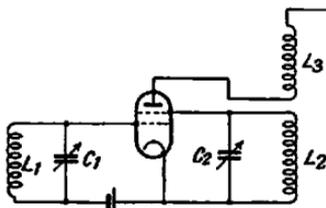


FIG. 44. BIGRID CIRCUIT

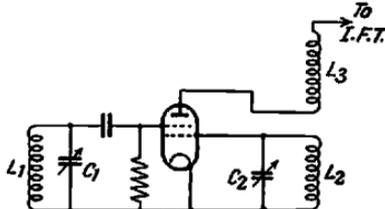


FIG. 45. ANOTHER BIGRID CIRCUIT

first grid, and anode working as triode, harmonic generation takes place and renders a receiver using this arrangement liable to harmonic interference. A bigrid valve working in the circuit of Fig. 44 gives only a small stage gain, so that it can hardly be considered an economy. By employing two separate valves, a higher gain can be obtained with less harmonic trouble.

Another circuit arrangement for use with the bigrid valve is seen in Fig. 45. In this case the incoming signal voltages are applied to the second grid, and the local oscillations are generated by back coupling between the anode and first grid circuits.

A rather interesting development of the bigrid valve is the twin-grid valve. There are two grids in this valve, but instead of one grid being behind the other with respect to the cathode, they are both in the same plane; they are electrically separate but mechanically intermeshed. One circuit devised by the inventor for use with this valve, and called the "Dupelidyne Circuit," is shown in Fig. 46. The input circuit connected to one grid is tuned as usual to the signal frequency, while the circuit joined to the other grid is resonant at the frequency of the oscillations generated by feed-back from the anode circuit over the coupling condenser C_3 . The intensity of the oscillations is varied by adjustment of resistance R , which alters the value of H.T. voltage

applied to the anode. Z is a high frequency choke. The anode circuit is coupled by condenser C_2 to the intermediate frequency amplifier.

The Screen-grid Valve. The screen-grid valve has been used very commonly as frequency changer, and has been found to work reasonably satisfactorily. Radiation is reduced to a low degree by coupling the tuned oscillatory circuit in the plate circuit to a coil in the cathode lead. The circuit coupled to the aerial is tuned to the incoming signal frequency, and if this circuit is sharply resonant only slight radiation will result.

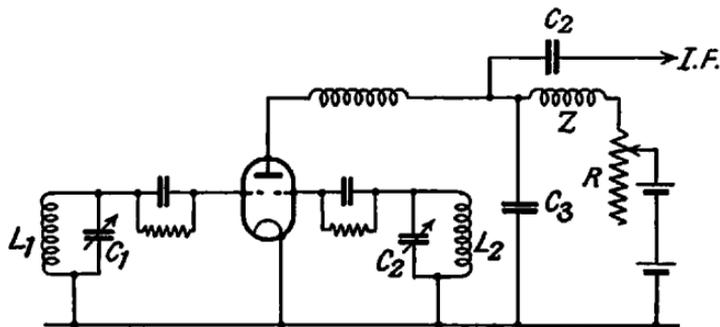


FIG. 46. THE DUPELIDYNE CIRCUIT

The circuit diagram is given in Fig. 47. The aerial circuit is coupled to coil L_1 tuned to the signal frequency by condenser C_1 , and anode bend rectification takes place as a result of the voltage drop along R , which makes the cathode positive with respect to the grid. The value of the condenser across R is not so large as normally, to prevent the tendency to squegger mentioned on page 62. Oscillations are generated by coupling L_2 to L_3 , the coil L_3 forming with C_3 a circuit tuned to the desired frequency of the oscillations. Condenser C_2 prevents the H.T. voltage from being short-circuited through coil L_3 , and coil L_4 is the primary of the intermediate frequency transformer.

It will be noticed that the oscillation circuit $L_3 C_3$ is in parallel with the primary of the I.F. transformer. One effect of this is that, as the latter is tuned to a frequency much lower than the oscillation frequency, it will act as a choke to currents of that frequency and of the signal frequency. This action facilitates the selection of the required intermediate frequency. At the same time there is a risk of reflection of resistance into the oscillator circuit if the latter should be tuned to an harmonic of the fundamental frequency of the I.F. primary coil. This difficulty is avoided by suitable design of I.F. and oscillator coils.

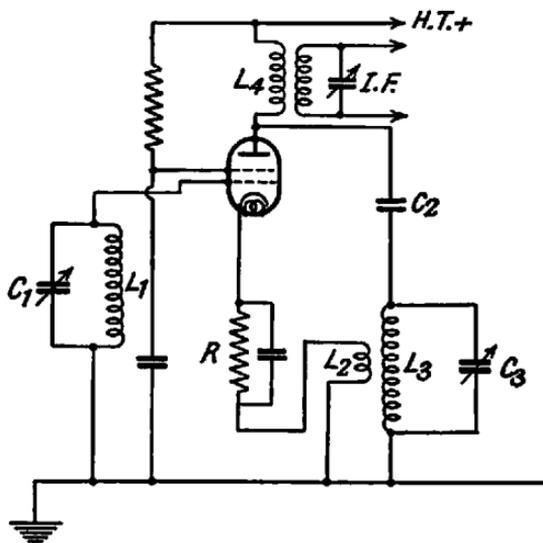


FIG. 47. CIRCUIT FOR USING A SCREEN-GRID VALVE AS FREQUENCY CHANGER

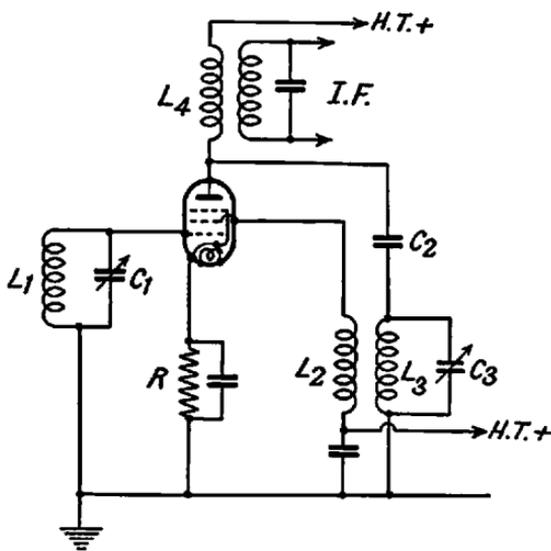


FIG. 48. A COMMONLY-USED CIRCUIT WITH THE H.F. PENTODE

There is interaction between oscillator and detector tuning circuits owing to the latter being in series with the reaction coil L_2 . Although this complicates the adjustment of the two circuits for satisfactory tracking, it is found that once this has been carried out and the condensers C_1 and C_3 are ganged, no further difficulties are encountered.

The High Frequency Pentode. One of the most successful frequency changer valves is the high frequency pentode, which is used very extensively. It has two important advantages over the screen-grid valve, namely, it can be used for a wider range of volume control, either manual or automatic, and there is less risk of radiation from the receiving aerial.

As mentioned in the chapter dealing with automatic volume control, variable μ pentodes are most suitable for effective control. For employment as frequency changers they are particularly valuable owing to the large input they will take without overloading or causing cross modulation. The overall gain of superheterodyne receivers is so great that usually some form of volume control in the input circuit is needed for reception of a local station or a powerful more-distant transmitter. The use of many types of volume control, however, often causes a certain amount of distortion. By employing a high frequency pentode, practically distortionless control of volume is obtainable.

Radiation from the aerial can be reduced by coupling the anode oscillation circuit to the screen-grid circuit instead of to the cathode lead of the input circuit, as is usual with a screen-grid valve.

In Fig. 48 is seen a diagram of one circuit that is suitable for the high frequency pentode. This arrangement is very similar to that shown in Fig. 47 for the screen-grid valve, with the exception that the reaction coil L_2 in this case is connected to the screen-grid instead of to the cathode. The result is a circuit that is very stable in operation and that does not radiate greatly, for interaction between the signal frequency circuit $L_1 C_1$ and the oscillation circuit $L_3 C_3$ is extremely small.

A circuit for the high frequency pentode that has been used in America is shown in Fig. 49. The circuit determining the frequency of the generated oscillations $L_2 C_2$ is now in the suppressor grid circuit, and is coupled to L_3 in the anode circuit which is in series with the tuned primary of the intermediate frequency transformer. This circuit is very stable in operation, owing to the shielding of the oscillator and signal frequency circuits by the screen grid, and the interaction between these circuits is very small. It should be noted that the low potential end of L_1 is not joined to earth, as is usually done, but is connected to a potentiometer in the cathode lead. There is thus effected a voltage drop between the signal

grid return and the earth wire. Since the suppressor grid is connected to the latter, it must be at a substantial negative potential with respect to the cathode. This arrangement is, in

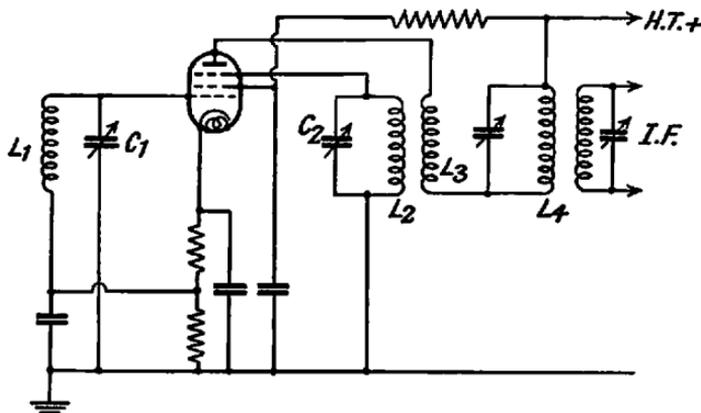


FIG. 49. FREQUENCY CHANGER CIRCUIT IN WHICH THE OSCILLATOR CIRCUIT IS CONNECTED TO THE SUPPRESSOR GRID

fact, an essential part of the circuit, as it is found that a high value of bias must be applied to the suppressor grid to enable it to control the plate current effectively.

It is not essential to connect the oscillation determining circuit in parallel with the primary of the intermediate frequency transformer. In fact, a very practical method of employing the H.F. pentode as frequency changer, and one that is used in a number of receivers, is to connect these circuits in series as shown in Fig. 50. Cathode injection of the oscillation voltage is utilized in this circuit.

Another arrangement that has been used fairly extensively is illustrated in Fig. 51, and is known as the *neutralized pentode* frequency changer. It may seem a retrograde step to have to resort to the use of a neutralizing condenser, but in practice its employment has been warranted by the improved performance and freedom from interaction between oscillator and preselector circuits, due to the more exact balancing of the inter-electrode capacities.

In this arrangement, the reaction coil $L2$ is connected in the screen-grid circuit, and feed-back takes place from the anode circuit. Only a very low screen-grid voltage is needed, and for this reason R has a high value so as to effect a substantial voltage drop from the H.T. + connection. The anode circuit is the

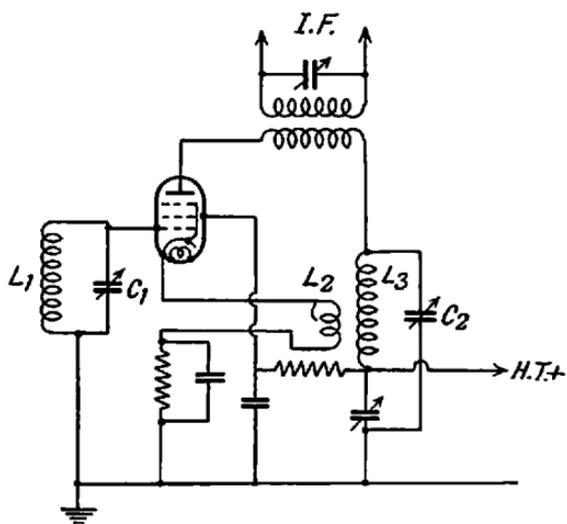


FIG. 50. PENTODE FREQUENCY CHANGER ARRANGEMENT IN WHICH THE OSCILLATOR AND I.F. PRIMARY CIRCUITS ARE IN SERIES

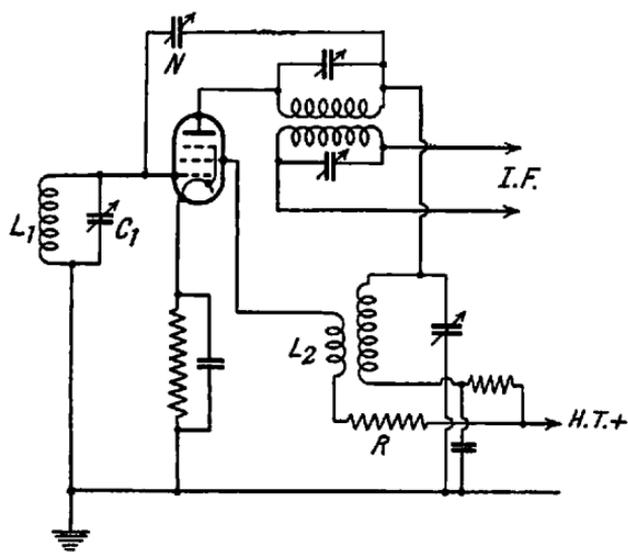


FIG. 51. NEUTRALIZED PENTODE CIRCUIT FREQUENCY CHANGER

commonly employed series arrangement of intermediate frequency transformer primary and oscillator circuit described above. Condenser N is the capacity for balancing the inter-electrode coupling.

The Hexode. This valve, which has four grids between the usual cathode and anode, is a recent development that is particularly applicable to frequency changing in a superheterodyne receiver.

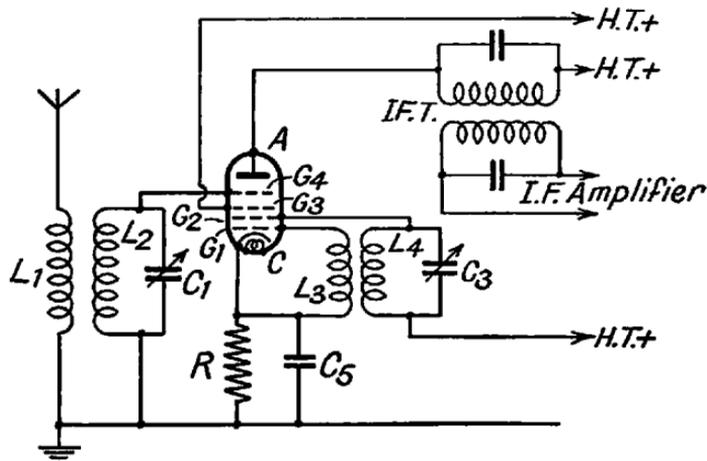


FIG. 52. HEXODE CIRCUIT IN WHICH GRIDS NEAREST CATHODE ARE USED AS OSCILLATOR

By virtue of the comparatively new mode of operation of this valve, it is possible to achieve a high degree of isolation between the detector and oscillator portions of the valve, and so rid the single-valve frequency changer for the first time of serious difficulties in connection with interaction between the two sets of circuits. The theory of operation of the hexode applies equally well to the pentagrid, for these valves are similar in many respects.

Suitable connections for this valve are shown in Fig. 52. Oscillations are produced by feed-back from the coil $L4$ in the circuit connected to the second grid (which is the oscillator anode) to coil $L3$ in exactly the same way as with an ordinary triode valve. The frequency of these oscillations is determined by the resonance of circuit $L4 C3$. This portion of the valve must be considered quite independently of the remaining part. It takes the place of a separate oscillator in the usual two-valve frequency changing circuits. Grid $G2$ (the oscillator anode) is not solid,

however, and consequently some of the electrons pass through it and reach the third grid. These electrons, once they leave the second grid, form the cathode current of the detector portion of the valve, the other electrodes being control grid G_4 , screen-grid G_3 , and anode A .

It is thus seen that the electron supply for the detector portion has first to pass through the oscillator valve. As a result, the electron stream will not be substantially constant as when it began its journey at the cathode C , but will be modulated in the cadence or rhythm of the oscillations produced by the oscillator portion. In effect, then, the electron source for the detector portion is a rapidly fluctuating one, and need only be further modulated by the incoming signals to produce the required intermediate frequency. The actual density of the cloud of electrons leaving the oscillator anode will obviously vary according to the instantaneous values of the voltages on the electrodes of the oscillator portion, and as these vary at the frequency of the oscillations, the density of the cloud will alter likewise.

Owing to the insertion of bias resistance R in the cathode lead, the grid of the detector portion will be at a negative potential with respect to the cathode. One effect of this is that the electrons passing through the oscillator anode are held in check until such time as the detector control grid is made positive. This occurs when high frequency currents are fed to the input circuit $L_2 C_1$ by the aerial. The electrons are then allowed to pass through the detector control grid and screen-grid to the solid anode A . The electron stream emanating from cathode C is thus doubly modulated, once by the oscillator portion of the hexode and then by the detector portion. This is known as electron coupling.

The operation of electron coupling is important in thermionic valve technique, and it might be as well to consider briefly the electrical significance of what is performed by this valve.

Electron Coupling. In all circuits used for frequency changing, some form of coupling must exist for applying the heterodyne oscillations to the mixer circuit in which they are combined with the signal currents. We have already examined circuits in which this coupling has been either inductive or capacitative. There are also conductive and resistive couplings, but these do not concern us here. The point to be noted about these coupling arrangements is that in all cases, *one part of the circuit is common*. As already mentioned, this results in interaction between the circuits, and also radiation from the receiver aerial unless special measures are taken to prevent it.

With electron coupling these difficulties are largely overcome, owing to the nature of the coupling, which is essentially different to the coupling used in other valve arrangements. The coupling

in this instance is electronic; that is to say, the effect of the local oscillations is added to the effect of the incoming signals through the common electron stream.

Now it should not be thought that, since there is a common electron stream, reaction between the circuits is bound to take place. Once some of the electrons pass through the oscillator anode, they have to wait for the detector control grid to become positive, or nearly so, before they can fly through to the detector anode. Any reaction that takes place must, therefore, be across this waiting electron cloud, and will affect neither the tuning of the associated circuits nor the coupling, for this latter has already been effected by varying the density of the electrons. The electrons that cannot be kept back by the grid will not pass to the aerial and so produce radiation, but will be attracted by the highly positive detector anode. Thus the two major evils of earlier single-valve frequency changers, namely, interaction between oscillator and detector circuits, and re-radiation, are largely reduced by the use of electron coupling.

So far, the behaviour of the hexode has not been considered in respect of that other objectionable feature of single-valve frequency changers—harmonic generation. In so far as the oscillator portion of the valve is completely separated in its operation from the rectifier portion, this is a distinct advantage, for the potentials applied to its electrodes can be adjusted so that the valve works more on the linear part of its characteristic. Even under such favourable conditions, however, it is difficult to operate a valve so that it does not generate some harmonics. The amplitude of the oscillations generated must exceed a certain minimum value, otherwise they will be of no use for frequency changing purposes. It is reasonable to assume, then, that some harmonics will be generated by the oscillator in addition to the fundamental frequency.

In discussing earlier in this book the prevention of trouble due to the generation of harmonics, it was mentioned that one effective remedy was the use of tuned circuits. Now this is precisely where the form of coupling used in the hexode leaves something to be desired, because it is quite unselective. Electron coupling, in fact, will pass on a second or fifth or n th harmonic just as efficiently as it will the fundamental. In practice this difficulty is not so serious as it might at first appear. As the oscillator portion can be adjusted quite independently of the detector, for efficient oscillation generation, the harmonic content will be small, and this is usually reduced to harmless dimensions by employing adequately selective circuits connected to the detector portion of the valve and in the intermediate frequency amplifier.

In order that the maximum advantage may be obtained from

the use of the hexode, steps must obviously be taken to see that no coupling exists between the various circuits exterior to the valve. By careful design, stray couplings between the circuits can be kept down to almost negligible proportions.

The basic hexode circuit shown in Fig. 52 is not the most practical, for owing to the inter-electrode capacity between the oscillator anode and detector control grid there is a certain amount of interaction between the circuits, which gives rise to instability and radiation. These defects can generally be overcome by the employment of a small neutralizing condenser between the oscillator grid and signal detector control grid.

In Chapter VII there is described a Telefunken receiver employing hexodes as H.F. amplifier, frequency changer, and I.F. amplifier respectively. The circuit arrangements used in that receiver are different from the circuit described here, and possess the great advantage that the oscillator circuit is screened from the signal frequency circuit.

The Pentagrid or Heptode. This valve, as the name "pentagrid" implies, has five grids. The title of heptode is not entirely satisfactory, for it merely implies a valve with seven electrodes. Such a valve was used some years before the introduction of the pentagrid, but instead of having five grids it had only two grids, and the valve itself was used as a neutralized push-pull amplifier. The pentagrid is one of the results of researches to produce a valve which will take its part in a superheterodyne as a single-valve frequency changer, and, in this capacity—

1. Will not permit radiation from the receiving aerial.
2. Avoids interaction between the oscillator and signal frequency tuning circuits.
3. Gives an appreciable stage gain.
4. Can be used effectively for volume control purposes.

These very desirable qualities are obtained partly by using electronic coupling as already outlined and in some circuits for the variable μ H.F. pentode, and partly by the employment of screening grids. In fact, as an examination of the circuit of Fig. 53 will reveal, the pentagrid is really a hexode plus a screening grid situated between the two portions of the valve associated with the I.F. circuits and the signal frequency tuning circuits. This extra screen-grid is of great importance, for it helps to keep the coupling between the various valve electrodes more purely electronic, and thus more independent of circuit alterations. It enables a nearer approach to be made to the ideal of complete isolation of the oscillator and detector circuits.

The oscillator portion ends at the second grid. After the electrons have passed through this grid (constituting the oscillator anode the same as in the hexode), they form the cathode current

of the detector portion. As the detector cathode stream they pass through the third grid (first screen-grid) and are controlled by the fourth grid to which the signal voltages are applied. The fifth grid is another screen-grid, and is connected inside the valve envelope to the third grid situated at the source of the detector cathode stream. This latter arrangement might at first sight appear similar to that of the suppressor (third) grid and cathode of a pentode. There is one very important difference between the two, however, and this is that in the case of the pentagrid valve the two grids joined together are maintained at a potential

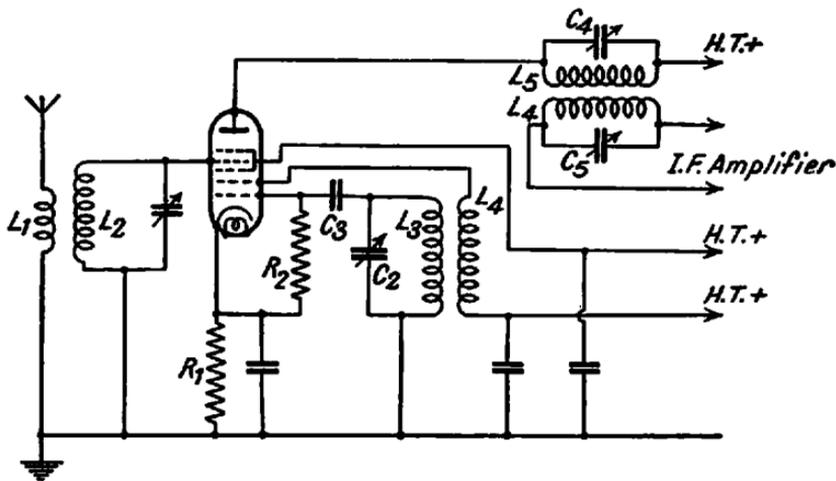


FIG. 53. CIRCUIT FOR USE WITH THE PENTAGRID

of about 100 volts positive with respect to earth, whereas with the pentode the two electrodes are joined to earth or a very low potential. The detector portion has variable μ characteristics, which are found to be very suitable for automatic volume control.

A circuit using the pentagrid valve is seen in Fig. 53. The input circuit is tuned to the signal frequency and the output circuit tuned to the intermediate frequency is $L5 C4$. The oscillator grid circuit $L3 C2$ is resonant at the required heterodyne frequency and, due to the coupling between $L4$ in the oscillator anode circuit and $L3$ in the oscillator grid circuit, oscillations are generated in the usual way.

The object of the grid leak and condenser is to even up the heterodyne voltage in the manner described on page 64. Some valve manufacturers recommend that the grid resistance be

connected across the grid condenser C_3 . In this case, the resistance acts as a current limiter and its value is critical, because if it is too high the feed-back from the oscillator anode will be ineffective, and if it is too low excessive grid currents will distort the heterodyne wave form and produce oscillator harmonics. A common value is 50,000 ohms. A further method of connecting the grid resistance is described in connection with the Philco Superhet.

From the foregoing it might appear that the pentagrid is the embodiment of all that can be desired in a frequency changer valve. There is, however, one aspect not yet considered. This is the effect of the pentagrid on the signal to noise ratio, which is of such vital importance in the superheterodyne receiver. From Fig. 53 it can be seen that any modulation of the electron stream by the oscillator portion of the pentagrid will be amplified by the detector portion. The latter is in effect a pentode valve and gives a high gain. Consequently, any extraneous noises, such as hiss, due to the oscillator, will be amplified to a large extent, and will tend to increase the background noise level. This constitutes a disadvantage to the use of the pentagrid valve, and is a subject that is receiving attention.

Another drawback to the use of the pentagrid is that under certain conditions there is a tendency to interaction between the oscillator and signal frequency circuits. This may occur during reception of short waves, when the operating conditions are such that the PERCENTAGE difference between the oscillator and signal frequencies is small. The cause of interaction is the manner in which the current from the H.T. supply is shared by the various electrodes at a high positive potential. It can be seen in Fig. 53 that there are four electrodes at a high positive potential, namely, oscillator anode, the two screens (grids numbers 3 and 5) and the main anode. Now, when the pentagrid is working the total current flowing in the circuits associated with these four electrodes is substantially constant, owing to the cathode emission being constant and unaffected by the signal input to grid 4. This is due to the interposition of the first screen grid (grid 3) between the cathode and signal control grid. This point will be clear from an examination of the curves shown in Fig. 43.

The interchange of space current between the various electrodes tends to create a certain amount of interaction and instability in the circuits. As mentioned above, these difficulties are not general. From the battery users' point of view, the constant current consumption of the pentagrid is not a blessing, for with other types of valves a negative potential on the control grid usually reduces the space current and, with this, the demands made on the H.T. battery.

The Octode. This valve is very similar in construction and working to the pentagrid, the additional electrode, to make eight, being a suppressor grid. The extra grid is situated next to the main anode, and is connected to the cathode inside the valve envelope as in the case of a pentode. The electrode sequence, beginning at the cathode stream emanating from the oscillator anode, is: screen-grid at positive potential, control grid, second

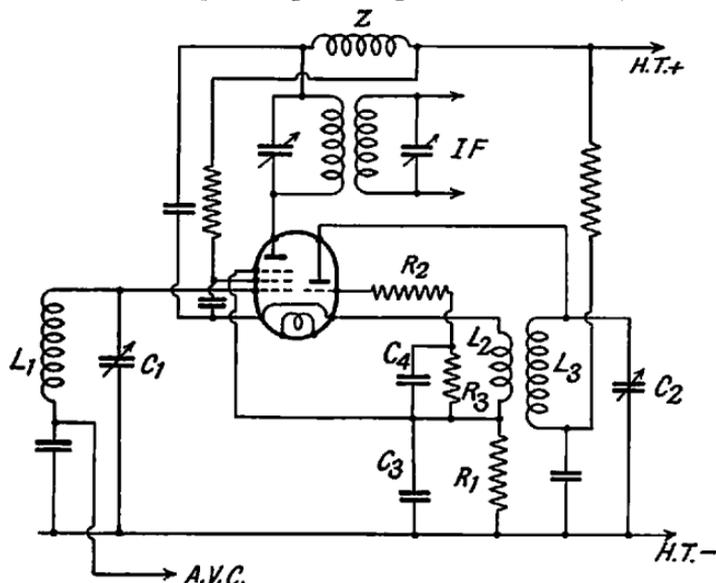


FIG. 54. THE TRIODE-PENTODE CIRCUIT USED IN THE "ULTRA 22" RECEIVER

screen-grid at positive potential (connected to first screen-grid), suppressor grid at cathode potential, and finally the anode.

The Triode-pentode. This valve is used in a large number of commercial receivers and is a serious rival to the heptode and octode for general favour, owing to its simplicity and stability in operation. Although the triode-pentode is in fact two valves within one envelope, a description of it is included in this chapter because it is generally referred to as a single valve.

The triode-pentode consists of a triode oscillator and a high frequency variable μ pentode first detector supplied by separate cathode streams from two parts of a common cathode. Unlike the pentagrid, these two sections are coupled outside the valve by the usual electro-magnetic or electrostatic devices. The triode and pentode sections are screened from each other inside the

glass envelope, so they may be considered as two separate valves coupled by a common cathode connection.

The circuit for the triode-pentode that is used in the Ultra 22 is given in Fig. 54. The input circuit $L1 C1$ connected to the pentode control grid is tuned to the desired signal frequency. The triode is worked as a tuned anode oscillator, the tuned anode circuit being $L3 C2$, while $L2$ is the cathode injection coil in the common cathode circuit.

The triode oscillator circuit is seen to consist of tuned anode circuit $L3 C2$, reaction coil $L2$, grid resistances $R3$ and $R2$ and condenser $C4$. Considering these elements only, the arrangement of $L3 C2$ and $L2$ is quite a normal one for the screen grid and pentode oscillators already described in this chapter. The connection of $R3$ (100,000 ohms) and $R2$ joins the oscillator grid to the cathode and not to H.T. —. One result of this is that the oscillator grid is biased by its own grid current flow along these resistances, so that the higher the voltage attained by the grid, the greater will be the negative bias applied. This tends to maintain a stable oscillator voltage, and no difficulty is experienced in practice in producing the optimum heterodyne within the desired limits. Condenser $C4$ is for the purpose of decoupling $R3$ from the effects of the high frequency currents. $R2$ acts as a kind of H.F. stopper to suppress oscillator harmonics and is usually about 2000 ohms in value.

In considering the oscillator circuit, no mention was made of $R1$, although at first sight this seems to be part of the oscillator circuit. Actually it is not, for the oscillator cathode circuit finishes at the connection of the grid resistance $R3$ at the top of $R1$ and is uninfluenced by the voltage drop along $R1$. However positive the cathode is made with respect to H.T. — by the presence of $R1$, the oscillator grid will be equally positive since it is joined to the cathode end of $R1$. Bias resistance $R1$ is, in fact, only in the circuit of the pentode, for the pentode grid return is joined to H.T. — and any voltage drop along $R1$ will make the cathode positive with respect to the pentode control grid. Condenser $C3$ is the usual bias resistance decoupling condenser.

The circuit shown in Fig. 54 is more or less standard for the triode-pentode, although the type of receiver to which it refers was marketed in 1934. Modern versions vary but slightly. Some receivers employ a resistance, about 40,000 ohms in value, across the oscillator anode coil to apply artificial damping and thus to maintain a more level value of dynamic resistance over the entire tuning range. Others do not use the oscillator harmonic suppressor $R2$.

It will be noted that the suppressor grid of the pentode is not connected directly to earth. If this were done the suppressor

grid would be biased negatively and would tend to flatten the tuning by reducing the pentode impedance. Nevertheless, some designs of receivers employ the earth connection for the suppressor grid.

Under practical working conditions the A.C. mains triode pentode gives a conversion conductance of 700 microamps per volt and will handle without distortion a signal carrier peak of 12 volts, modulated at 60 per cent. The optimum heterodyne is 3 volts.

Triode-hexode. This type of valve has been used to some extent in Germany and has now been introduced into this country. It comprises a hexode valve, employed as mixer, and a triode valve as oscillator. This arrangement should not be confused with the triode-pentode, for in the latter case the coupling between oscillator and mixer is by externally connected coils, whereas in the triode-hexode electronic mixing is employed by connecting the triode oscillator grid to the third grid (counting from the cathode) of the hexode. Oscillatory voltages from the triode are thus impressed on the cathode-anode electron stream of the hexode and reactionless electronic mixing is effected. The hexode portion of the valve has variable μ characteristics, and can therefore be used for automatic volume control if the control voltages are impressed on the signal grid.

The connections of the hexode are as follows: Between the first grid, counting from the cathode, and the cathode, input signal voltages are applied by the usual resonant circuit. The second and fourth grids are connected together, inside the valve envelope, to act as screens, while the third grid is joined to the triode oscillator grid and is the mixing electrode. The triode connections are those of a straightforward feed-back oscillator, with the cathode joined to that of the hexode.

These connections are clearly seen from Fig. 55, which shows the most commonly used circuit for the triode-hexode. A usual value of grid leak R_1 is 50,000 ohms, and grid condenser C_3 , $0.0001\mu\text{F}$. Resistance R_2 is for the purpose of limiting the oscillator voltage, which in the case of the Marconi X41 should be maintained at 25 volts for optimum conversion conductance. In practice, the value of R_2 is a few hundred ohms, say from 100 to 500 ohms. A damping resistance R_3 is shown connected across the tuned oscillator circuit and works in a similar manner to the damping resistance described in connection with the triode-pentode on page 93. The value of R_3 may vary from 10,000 ohms to 50,000 ohms.

The principal curves setting forth the characteristics of the Marconi X41 are given in Fig. 56. These curves should be compared with the corresponding curves in respect of the heptode

on page 79. The following essential differences are apparent—

1. As the control grid bias is increased the screen current falls with the reduced anode current in the case of the triode-hexode, whereas with the heptode the screen and oscillator anode current rises as the main anode current is reduced.

2. The conversion conductance when a low bias voltage is applied to the control grid of the triode-hexode, is very high (up to nearly 1000 micro-amperes per volt) but with the MX40

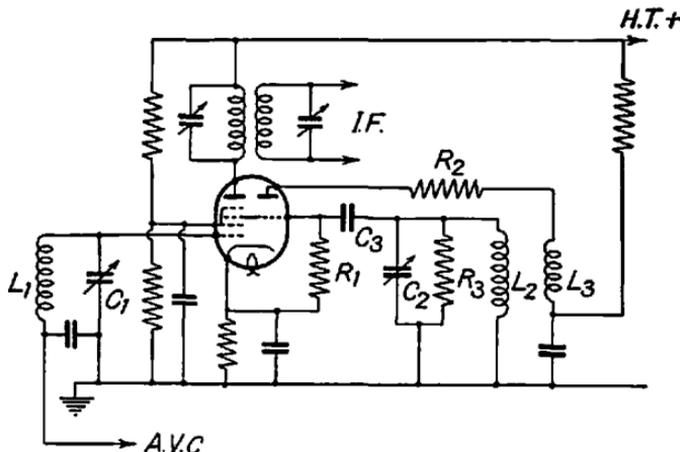


FIG. 55. CIRCUIT FOR THE TRIODE-HEXODE

heptode the maximum conversion conductance is about $500 \mu A/V$ and this is diminished as the grid bias is increased.

3. With the triode-hexode, the oscillator anode current remains sensibly constant over the entire range of hexode control grid voltage. The oscillator anode current of the heptode, however, varies considerably as the control grid voltage is altered.

The first of these points is of significance to battery users, for with the triode-hexode, when a loud signal is being received and a high grid bias is applied to the signal control grid, the total anode and screen current consumed by the valve is greatly diminished.

The second point is not so important in practical reception as it might seem at first, owing to the necessity to work the valve with a minimum control grid bias. In the case being considered the normal bias is -1.5 volts, giving a conversion conductance of $550 \mu A/V$. Under these circumstances, the part of the conversion conductance curve above the point marked with a cross will not be employed. Probably the most important difference between the working of the triode-hexode and the heptode is

the third one given above regarding the complete independence of the oscillator anode current in respect of the control grid

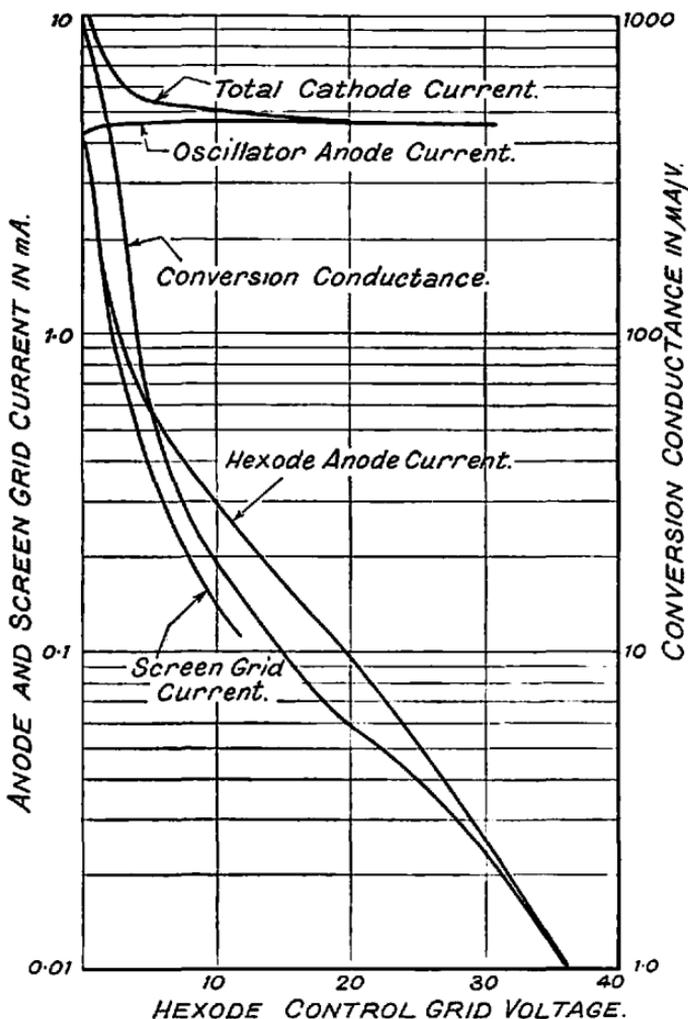


FIG. 56. CHARACTERISTIC CURVES OF THE TRIODE HEXODE

voltage. It has already been mentioned that with the heptode the inter-dependence of oscillator anode and screen grid currents on the one hand and the main anode current on the other results

in "pulling" or interaction between oscillator and signal circuits during reception on short wavelengths.

Owing to the separation of the oscillator and mixer valves in the triode-hexode, this disability of the heptode has been reduced, for not only are the oscillator and hexode electron currents independent, but in addition the inter-electrode capacity between the oscillator anode and the hexode electrodes is rendered so small as to be harmless down to very short wavelengths.

CHAPTER VI

AUTOMATIC VOLUME CONTROL

ALTHOUGH automatic volume control of reception has nothing to do with the principles of a superheterodyne receiver, it was mainly owing to the development of the latter that some kind of automatic control became a necessity. This survey of the superheterodyne receiver would be incomplete without a section on automatic volume control, for no modern receiver of this type with any pretensions to satisfactory reproduction of foreign station programmes is without it. In fact, the time is not far distant when all receivers, except possibly those used for local station reception, will include such a device.

The need for some kind of arrangement that will even out the large fluctuations in the intensity of the reproduction from the loudspeaker during reception of a distant station, is apparent to anyone who has listened to such a broadcast. The variations in signal input due to fading are quite unavoidable. They result from the combined effect at the receiver of two components of transmitted signal; one due to the direct ray, as generally received during the daytime, and another due to the indirect ray that has taken a circuitous route via the Heaviside layer. The indirect ray at the receiver is continually varying in phase relative to the direct ray owing to the movements of the Heaviside layer, which reflects it. As a consequence, the effective voltage fed to the receiver will vary according to the phase of the two incoming waves, being a maximum when they are exactly in phase and a minimum when they are 180° out of phase. If the amplitude of the two component waves is the same and they are of opposite phase, the net voltage induced into the aerial will be zero.

One method of overcoming the effects of this phenomenon is the use of more than one aerial. In Chapter VII Marconi's Diversity Receiver is described, which makes use of two aerials and has been in successful operation for some time. This method, however, is entirely impracticable from the home broadcast receiver point of view. The system at present in general use for this purpose is comparatively inexpensive, and gives satisfactory results. Although automatic volume control does not effect a perfect evening-up of loudspeaker intensity, it does go a considerable way towards this ideal. When it is remembered that voltage variations on an aerial may vary in the ratio of one to a million, the difficulty of producing a perfectly constant output will be appreciated.

Another rather unpleasant experience in reception that is eliminated by the use of automatic volume control is the sudden enormous increase in loudspeaker volume that occurs with consequent "blasting," if, while searching for a distant station with the manual volume control set for maximum sensitivity, the local or a powerfully received station is passed over by the tuning dial. This cannot happen when automatic control of volume is employed, for the local station output at the receiver is brought down to approximately the same level as a distant station.

It should not be supposed from what has been written above that the "light" and "shade" of music is lost. In a given programme there will be loud and weak passages in exactly the same way as without the control, for the component of the incoming signal that operates the control is the carrier wave. The part of the signal that determines the strength of a particular passage is the sideband amplitude, and this has no effect on the control.

There are certain disadvantages in the employment of automatic volume control. One is that it accentuates fading distortion. This kind of distortion is caused by the uneven fading of the various frequencies comprising the carrier and sidebands, as a result of which the musical frequencies reproduced do not bear the correct ratio of intensity to each other. Another drawback is the great increase in mush and atmospheric noises while tuning. As a station is passed over by the tuning dial the overall sensitivity of the receiver will increase until, midway between two stations, it will be at maximum sensitivity. The background noise will then be at its loudest. There is a method of overcoming this, called *quiet automatic volume control* but it usually involves the use of an extra valve, and is therefore only in use on the more expensive receivers. A further disadvantage of automatic volume control is the peculiar effect of the receiver sensitivity rising and falling to cope with signal input variations during fading. The net effect is that of moving the tuning dial from the point of reception of a station to one off-tune, so far as the background noise is concerned, but the signal output, of course, remains sensibly constant.

While listening to a station under these circumstances the noise level rises and falls while the signal is maintained at the same intensity.

Theoretical Considerations. The basic principle underlying the operation of automatic volume control is that, if the rectified current from the detector valve be passed through a resistance, a D.C. voltage drop will be produced which, if applied to the high frequency valves as grid bias, will control their effective amplification. A voltage drop along a resistance is equal to the product of current by the resistance. It is clear then that the larger the current flow, the higher will be the voltage applied as grid bias

to the amplifier valves, and consequently the lower will be the effective amplification. It is merely an automatic way of varying grid bias applied to a variable μ valve instead of the operation being done manually as is usual with receivers without this device. Variable μ valves are essential for the satisfactory operation of automatic volume control, for the amplification characteristic of the normal type of screen-grid valve is unsuitable for control by this method. Cross modulation is likely to be experienced if the grid bias of a screen-grid high frequency amplifier valve is varied over a wide range.

There will be fluctuations in the rectified current flow along the resistance in the detector circuit, owing to slight variations due to the presence of low frequency currents. It is necessary, therefore, to smooth or filter the voltage applied as bias to the controlled valves. For this reason filter devices are an integral part of automatic volume control arrangements, and will be seen in all the circuits about to be described.

Another point to be noted is that more than one valve must be controlled if really effective constancy of output is desired. The possible control with two valves is proportional to the square of the voltage due to the rectified current flow along the control resistance, and to the cube of this voltage if it is applied to three valves. With amplified automatic control, a greater degree of control is obtained, but even then more than one controlled valve is desirable. The control should be so adjusted that the receiver is enabled to deliver something approaching its maximum output.

Diode as Control Valve. A diode rectifier valve is often employed for the purpose of supplying the control current. This is because the diode is capable of handling much greater voltage without overloading than a triode or screen-grid detector valve. It is important that the detector valve feeding the control resistance be capable of handling a considerable input voltage without introducing distortion, since the grid bias range required for effective control of the average variable μ valve is from 2 to about 30 volts, and the input to the detector, on the assumption that 100 per cent efficiency will be given by the rectifier, must be of the same order. One disadvantage of using a diode detector is that as it is only about one-twenty-fifth as sensitive as a triode working as grid or anode bend detector, extra amplification is needed to compensate for this loss of sensitivity.

The basic circuit for connecting a diode to function as combined detector and control valve is seen in Fig. 57. Coil L_1 , to which are supplied currents of the intermediate frequency (or high frequency in the case of a straight receiver), is coupled to L_2 tuned by C_1 and connected to the diode anode at one end. The

opposite end of L_2 is joined to the cathode through a resistance R_1 and by-pass condenser C_2 .

When a signal is received, the input to the diode is rectified and passes along R_1 to produce a voltage drop along it. This voltage

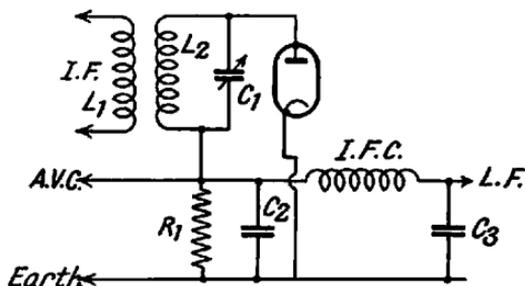


FIG. 57. DIODE AS RECTIFIER AND CONTROL VALVE

is applied to the variable μ valves as control bias. I.F.C. is an intermediate frequency choke, and condenser C_3 is to by-pass the intermediate frequency current that is still in the circuit, for if this current were allowed to reach the controlled amplifiers it would be re-amplified and cause instability.

A double-diode circuit for combined detection and volume control is shown in Fig. 58. Here, both the half-waves of the

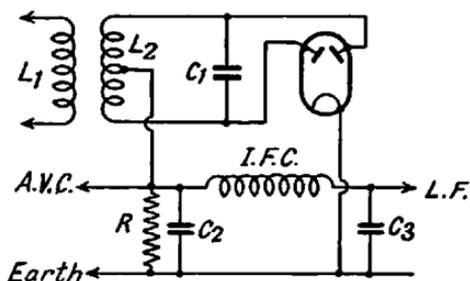


FIG. 58. DOUBLE DIODE AS FULL-WAVE RECTIFIER AND CONTROL VALVE

signal currents are rectified and greater efficiency is obtained. Apart from the fact that the cathode tapping on coil L_2 must be at the exact electrical centre, which is not necessarily the mechanical centre, this circuit calls for no comments, as its operation is similar so far as the A.V.C. is concerned, to the circuit of Fig. 57. It should be noted, however, that owing to the centre

tapping along L_2 the H.F. currents present after detection will be cancelled out due to their being applied in opposite phase to R .

Delayed Volume Control. It can be seen from the last two diagrams that *any* signal, no matter how weak, so long as it produces a rectified current, will cause an increase in bias to be applied to the controlled valves, since this voltage is directly proportional to the current flow along R . This is a disadvantage, for it means that when even a moderately weak station is being received, quite an appreciable bias will be placed on the variable μ valves, and the amplification may not be as great as desired.

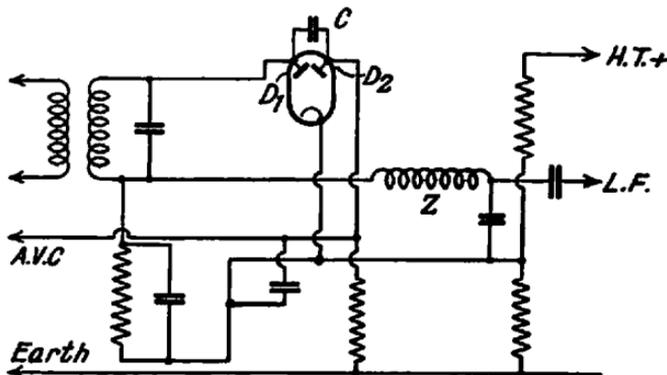


FIG. 59. BASIC CIRCUIT FOR USING A DOUBLE DIODE AS DELAYED A.V.C. VALVE

Clearly, then, the most practical arrangement is one in which the increased bias for the controlled valves is not applied until the incoming signal is of such an intensity that it will operate the loudspeaker at the desired volume.

A circuit for achieving this object is shown in Fig. 59. This arrangement is known as *delayed volume control*. The signal rectifier diode anode is D_1 , and the control diode anode is D_2 . Intermediate frequency currents in the input circuit are rectified by diode D_1 , and currents proportional to the signal voltage are supplied to the L.F. amplifier through choke Z in the usual way, no use being found for the potential existing across the load resistance due to the D.C. component. Diode D_2 also rectifies the signal currents, which are supplied to it over C , but owing to the negative bias the anode receives from being connected to the earth line rectification cannot take place until the signals have reached a certain strength. In this case the D.C. component of the rectified current is used for control bias, while the low frequency currents are by-passed by a condenser.

screen-grid detector. This is because these latter valves do not merely rectify but amplify at the same time, whereas the diode is only a rectifier. This drawback to the use of the diode has been overcome by constructing valves which comprise not only the rectifier and control diodes, but also an amplifier valve for the audio frequency currents.

There are two types of such valves, known as the *double-diode-triode* or *duo-diode-triode* and the *double-diode-pentode* respectively. As their names imply, they comprise, in the former instance, two diodes and a triode amplifier valve, and in the second case two

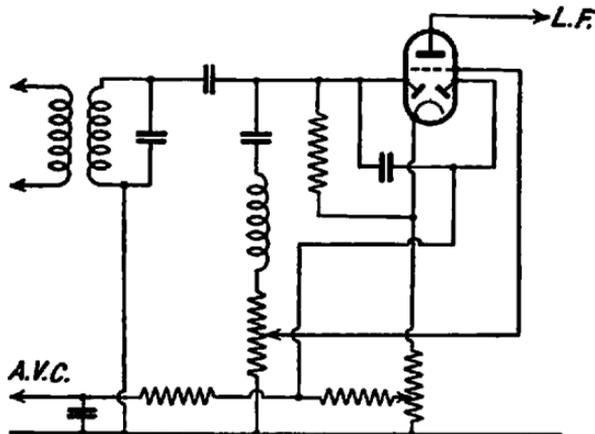


FIG. 61. DOUBLE-DIODE-TRIODE CIRCUIT FOR OBTAINING RECTIFICATION, DELAYED A.V.C., AND L.F. AMPLIFICATION

diodes and a pentode. The triode portion is of the HL type; that is to say, it has a fairly high amplification factor.

In Fig. 61 is shown a circuit in which a double-diode-triode supplies delayed control voltages and amplifies the low frequency signal currents. The I.F. voltages are impressed on the diode and rectified in the usual way, L.F. impulses passing over the condenser, choke and potentiometer in series across the I.F. input circuit. By means of the adjustable connection of this potentiometer the low frequency currents are applied to the grid of the triode valve, which amplifies these signal currents and passes them to the next stage, usually the output stage. The object of having a variable tapping along the potentiometer is to enable the volume of the loudspeaker reproduction to be varied without altering the A.V.C. adjustments. This device forms an easy and effective manual control. The control diode anode

is connected by a condenser to the signal diode anode, and is also joined to a tapping along the cathode resistance that normally supplies the triode grid bias. This diode tapping is adjusted to give the requisite negative bias to the A.V.C. diode so that the latter is not operative and no control voltages are produced until signals of a predetermined intensity are received. The strength of signals that actually operates the A.V.C. system is dependent upon the position of the diode tapping along the cathode resistance, the higher the bias the stronger being the required signals.

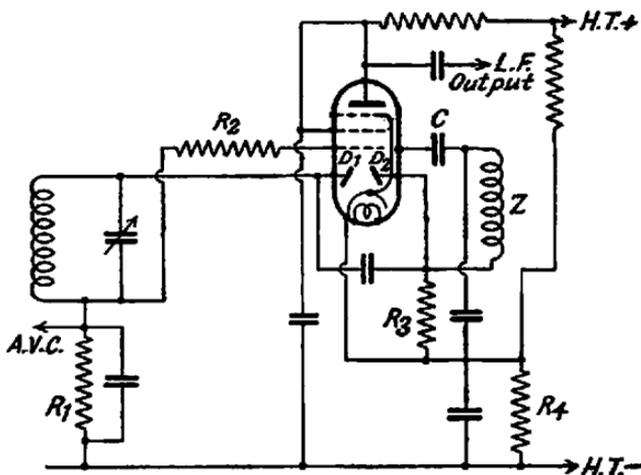


FIG. 62. ONE CIRCUIT FOR CONNECTING THE DOUBLE DIODE-PENTODE TO EFFECT A.V.C. ON ITSELF IN ADDITION TO THE PREVIOUS STAGES

Several of the receivers described in the last chapter employ a double-diode-triode.

The double-diode-pentode is usually connected to give half-wave rectification from one diode, A.V.C. voltage from the other diode, and L.F. amplification by the pentode portion. As the gain obtainable from a pentode is much greater than that from a triode, this arrangement enables a more sensitive receiver to be designed using a given number of valves. There is, however, another and far more important reason for the employment of the double-diode-pentode. This is that it can be made to produce control voltages not only for the high frequency valves, but also for a low frequency amplifier, the latter being the pentode portion itself; and in so doing it avoids any tendency of the valve to overload during the reception of a strong input voltage. The

pentode must, of course, be of the variable μ type so as to allow of effective control. A circuit for connecting a double-diode-pentode is shown in Fig. 62. It will be noted that diode $D1$ acts as volume control valve, the voltage drop down $R1$ being applied to the high frequency stages through the usual arrangements, and to the control grid of the pentode portion through $R2$. This variable bias for the pentode is in addition to that produced by

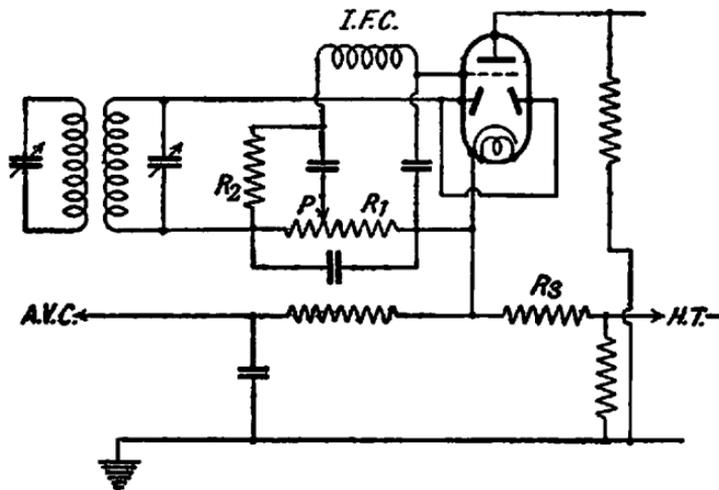


FIG. 63. CIRCUIT FOR OBTAINING AMPLIFIED A.V.C.

the drop down $R4$, which is for the purpose of providing a minimum bias. Diode $D2$ rectifies the signal and causes audio frequency voltages to be developed along $R3$, these being applied to the control grid of the pentode through a high frequency choke Z and condenser C .

In Chapter VII the "Faraday All-wave Receiver," which makes use of a double-diode-pentode, is described. It will be noted that the circuit arrangement employed in this receiver is different to the circuit given in Fig. 62.

Amplified Volume Control. In receivers employing only one or two stages that can be controlled (I.F. or H.F.), some difficulty in obtaining a constant output is experienced with the A.V.C. systems previously mentioned, owing to the necessity for applying such a large input to the detector in order to produce a D.C. output large enough for satisfactory biasing purposes. For receivers of this type an arrangement has been devised in which amplified control voltages are used for biasing purposes.

One circuit for giving amplified A.V.C. is shown in Fig. 63. The incoming signals are rectified in the usual way, and pass along the load resistance R_1 to be tapped off by P and applied to the grid of the triode portion of the valve, while the D.C. component due to the carrier wave is applied to the triode grid through R_2 . The resistance R_3 constitutes the load resistance of the triode, and the voltage developed along it by

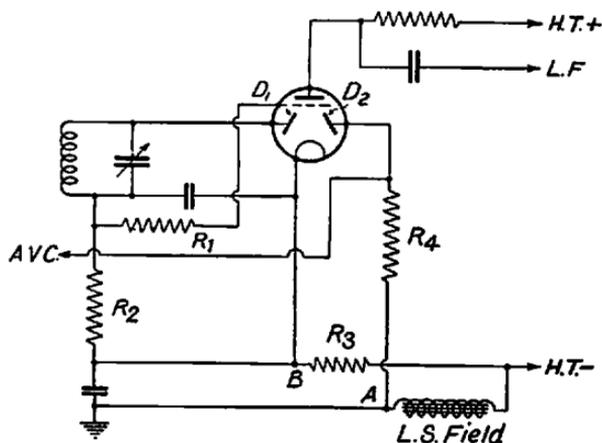


FIG. 64. METHOD OF OBTAINING DELAYED AMPLIFIED A.V.C.

the anode current flow is applied to the controlled valves as grid bias.

Delayed Amplified A.V.C. The circuit for amplified volume control just described suffers from the same defect as the simple A.V.C. circuit of Fig. 57, i.e. it will operate on a weak signal when no control is desired. A practical circuit employs a delayed action, and one method of achieving this with amplified A.V.C. is illustrated in Fig. 64. The triode load resistance is again R_3 , but in this case the control voltage is obtained from diode anode D_2 .

The working of this commonly used circuit is as follows: voltages at the intermediate frequency are applied to the signal diode and rectified in the usual way, L.F. impulses passing along the signal diode load resistance R_2 . To the grid of the triode section are applied the L.F. voltages via R_1 , and also the D.C. potential developed along R_2 by the signals. Up to a point, therefore, the bias applied to the grid will be dependent upon

the strength of the incoming signals, and likewise will be dependent also the triode anode current flow and the voltage drop it produces along *R3*. The voltage at point *B* will therefore be positive with respect to the H.T. — lead to an extent corresponding to the signal strength.

Now, the A.V.C. diode is connected through its load resistance *R4* to the loudspeaker field and thence to the H.T. —. As the total anode current of the receiver flows through the loudspeaker field, a voltage drop is produced along it that is not materially affected by alterations in the individual anode currents. This drop may therefore be considered as constant, and to produce a positive potential at point *A* with respect to H.T. —. It is noted that *D2* is connected to *A* (via *R4*) and owing to this connection it would, if *R3* were not in circuit, be maintained at a constant positive voltage. However, owing to the presence of *R3*, the cathode is also given a positive voltage, and unless the positive potential of *D2*, i.e. at point *A*, is greater than that of the cathode, i.e. at point *B*, no current can be passed by *D2* and no A.V.C. voltage is obtained from it. The net result of this arrangement is that the voltage of *D2* with respect to the cathode is dependent upon the relative voltage drops along *R3* and the loudspeaker field.

When a strong signal is being received, the anode current due to the triode section of the valve is reduced owing to the larger bias applied to the grid along *R1*. Consequently the voltage drop down *R3* is diminished, and with it the positive voltage of the cathode. This makes *D2* relatively positive owing to the voltage due to the current flow in the speaker field. When a weaker signal is received, the anode current flow along *R3* may not be reduced sufficiently to diminish the positive voltage at *B* to a lower value than that at point *A*, and in this case, since *B* will be more positive than *A*, *D2* is held at a negative voltage with respect to the cathode and no current is passed by it. As soon as the required threshold value of signal voltage is impressed upon the grid, *B* becomes less positive than *A*, the A.V.C. diode becomes operative, and the negative voltage applied to the A.V.C. line will be approximately that of point *B* relative to point *A*.

It should be observed that in this arrangement, the A.V.C. diode *D2* does not act as a rectifier valve as in the examples already shown in respect of other types of A.V.C. circuits, but more as a switching device that is operated automatically by the relation of the voltages at points *A* and *B*. Another feature about this circuit is that the actual voltage obtained for A.V.C. purposes is much greater than the D.C. bias voltage applied to the grid of the triode section of the valve.

Controlled H.F. and I.F. Valves. So far, only the production of the control voltage has been considered. The method of application of this voltage to the controlled valves now calls for consideration.

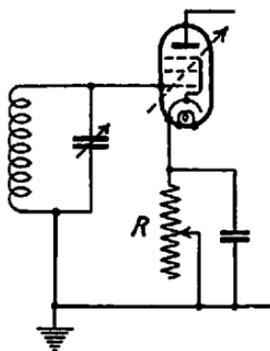


FIG. 65. THIS SHOWS THE USUAL BIASING ARRANGEMENTS OF A VARIABLE- μ VALVE FOR MANUAL CONTROL

A conventional circuit for a variable μ valve is seen in Fig. 65. In the cathode lead to the common earthed wire is placed a resistance R , the value of which is so adjusted that the current flow along it produces a voltage drop, and thus makes the cathode positive with respect to the grid, so that the grid in effect is negative to the cathode and the required bias is obtained. Resistance R is normally adjustable by hand, so that any desired level of response from the loudspeaker within the power of the receiver is obtainable. The relation of mutual conductance and grid voltage in the function of a variable μ valve is such that a very wide range of voltage amplification is obtainable by suitable adjustment of the grid bias.

In automatic volume control systems, the fluctuating voltage applied to the variable μ valve is provided by the methods already outlined. The conventional resistance R , then, is not needed except for the purpose of applying a minimum bias independently of that received from the automatic control arrangement. A manual control can still be used in the normal position, if required, for adjusting the general level of sound given by the loudspeaker.

The usual arrangement of the controlled valve is seen in Fig. 66, where a minimum bias resistance R_1 is inserted in the cathode lead. Control voltage is led to resistance R_2 which serves the dual purpose of decoupling and filtering, and is applied to the grid through the tuning coil. Condenser C is essential to block the path to earth against the control voltages, but at the same time to provide a low impedance path for the signal currents.

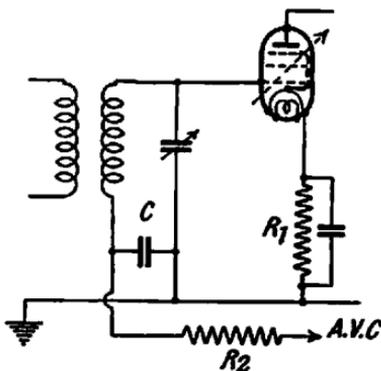


FIG. 66. CIRCUIT FOR APPLYING AUTOMATIC CONTROL VOLTAGE TO H.F. PENTODE

R along which a current will flow at a strength depending upon the input current. The voltage drop due to this current is utilized for control purposes, and is fed over choke Z_2 to the variable μ valves in the usual way.

It will be noticed that the anode of the control valve is the point from which the control negative bias is taken. This anode is, in fact, at a negative potential with respect to the earth wire, owing to the voltage drop down R , but is positive with respect to its cathode due to the connection of the latter to the H.T.-end of a resistance. For anode bend detection a negative bias is required, and so an additional resistance is added in the H.T.-lead, and a variable tapping is joined to the grid to enable the best working point to be obtained.

There are two drawbacks to the arrangement shown in Fig. 67. One is that extra H.T. voltage is required, since the voltage drop down the resistances used for the control valve is in series with the voltage applied to the anodes of the other receiver valves. Another disadvantage is that, as the control valve cathode is at a voltage negative with respect to earth by an amount equal to the voltage drop down R , a separate heater winding is needed in order to eliminate the risk of a breakdown of insulation between heater and cathode.

Quiet Automatic Volume Control. At the beginning of this chapter reference was made to the accentuation of background noise that usually results from the employment of automatic volume control at the receiver. This is particularly noticeable while tuning between stations owing to the receiver then being at maximum sensitivity. This increase in sensitivity is only useful up to a point, for a signal to possess definite entertainment value must be of a certain intensity. The sensitivity of the receiver, then, that brings in signals weaker than that of the minimum intensity demanded for programme enjoyment, is not only of no value, but is a serious drawback inasmuch as it increases the background noise. An ideal receiver in this respect would receive only those stations which were capable of being reproduced at a strength giving an entertainment value, all other signals, including background noises, being excluded from the loudspeaker.

That is the object of a system of control known as *quiet automatic volume control* or inter-station noise suppression. In this system, the low frequency amplifier valve is arranged to be blocked (by the application of a high grid-bias voltage) when signals below a predetermined level are picked up by the receiver. The level below which the receiver is inoperative can be determined by the listener, so that at one extreme, only a powerful local station can be heard, and at the other extreme, the receiver is working at full sensitivity as with ordinary automatic volume control.

One of several arrangements for bringing about this very desirable state of affairs is shown in Fig. 68. The first valve supplies the "quiet" control voltages, and the second is a L.F. amplifier. The control grid of V_1 is connected to the source of the normal A.V.C. voltages, so that its voltage will rise and fall with the control voltage applied to the high frequency stages. When no signal is being received there is no control bias voltage applied to this grid, and consequently the anode current of valve V_1 is heavy. The anode current flowing along R_1 produces a voltage drop which is applied to the control grid of the L.F. valve as negative bias, this bias being sufficient to block completely the

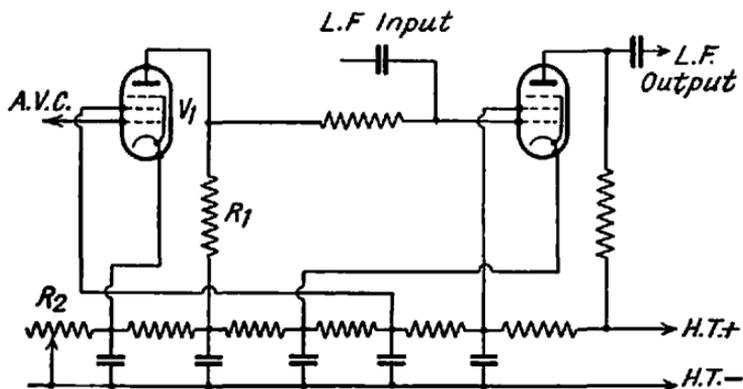


FIG. 68. ONE CIRCUIT FOR EFFECTING QUIET A.V.C.

electron path through that valve and render the valve inoperative. When signals are received, the A.V.C. voltage applied to V_1 increases and the current through R_1 thus diminishes, and with it the bias of the L.F. valve. After the control voltage to V_1 has reached a certain value, the bias applied to the L.F. valve is so low, due to the reduced current flow through R_1 , that this valve is again operative and the signal can be heard in the reproducer.

The signal intensity below which the L.F. valve is blocked is determined by the amount of R_2 in circuit. This resistance, it will be noticed, forms the self-bias resistance of V_1 . Consequently, if its value is made large, V_1 will be heavily biased and little anode current will flow along R_1 to bias the L.F. valve. Under these circumstances the receiver will be very sensitive and weak signals will be receivable. If the amount of R_2 in circuit is reduced to a low value, a large current will flow along R_1 to produce a high bias voltage for the L.F. valve. As a result this valve will be blocked except when the signal being received is strong enough to

bias V_1 to such an extent that the anode current flow is considerably diminished.

There are other methods of achieving quiet automatic volume control. One involves the employment of two double-diode-triodes, and another utilizes a relay which can be adjusted to bring the "quiet" control into operation at varying degrees of receiver sensitivity. An example of the latter system of control is seen in the R.G.D. radio-gramophone described in Chapter VII. See also the description of the Pye T21 receiver.

Use of a Single Valve for Obtaining Quiet, Amplified, and Delayed A.V.C. A new valve has recently been introduced to the market designed to effect quiet, amplified, and delayed A.V.C. This valve has three diodes and a triode, and is called a *triple-diode-triode*.

That one valve can be made to carry out all requirements for an A.V.C. system is a great advantage, for hitherto the fitting of a device to obtain quiet control has involved a comparatively great expense. This new valve enables quiet control to be obtained on the lower-priced models of superheterodyne receivers.

The three diodes work independently, one for signal detection, one for delay, and one for suppressing all signals below the predetermined strength. The signal diode connected to the secondary of the intermediate frequency transformer is returned via its load resistance to the delay diode, and both are biased to obtain the required delay.

Quiet control is effected by the remaining diode which receives signal voltages from the preceding I.F. valve anode. These signal voltages are rectified by the quiet diode and applied (i.e. the D.C. component) to the triode grid as extra bias. This causes a decrease in triode anode current flow, and consequently a reduction in the voltage drop along the cathode circuit resistance elements which tends to neutralize the delay voltage. When the bias applied to the triode grid is high enough (due to the reception of a strong signal), the anode current flow is so greatly reduced that the diminished voltage drop in the cathode circuit completely neutralizes the delay bias and the A.V.C. system is allowed to operate. As *both* the delay and the signal diodes are biased, however, neither can operate until the bias is removed by the reduction in triode anode current flow, and hence no signal rectification and consequent reproduction takes place until this condition is satisfied.

Metal Rectifier as Control Element. The high frequency metal rectifier, known as the "Westector," is used in some receivers for the purpose of producing the automatic volume control voltages. One such type is the Marconiphone Portable Superhet Type 269, described in Chapter VII.

In some respects the Westector, frequently termed a *metal diode*, is similar to the thermionic diode. It has a linear characteristic, and will handle a very large voltage input without overloading—a quality of the second detector that is essential for satisfactory A.V.C. purposes. The “double diode” can also be used with a centre-tapped input inductance, thus enabling a greater degree of filtering of the intermediate frequency to be effected in exactly the same manner as for the double thermionic diode. It possesses

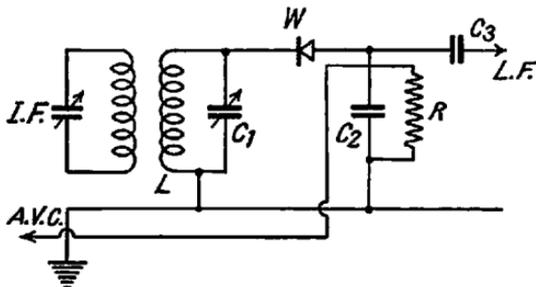


FIG. 69. A SIMPLE METHOD OF USING A WESTECTOR AS SECOND DETECTOR AND A.V.C. DEVICE

the advantage of being more compact and light than its thermionic counterpart, and owing to no anode or heater current being required it is often used in portable receivers.

The Westector must be so arranged that there is a direct current path round the circuit consisting of rectifier, input circuit inductance, and load resistance. In Fig. 69 these parts are lettered *W*, *L*, and *R* respectively. It would be impracticable, for example, to connect a condenser in this circuit as is usual with grid thermionic valve detectors.

A circuit for using a metal rectifier as control element is shown in Fig. 69. Circuit *L*, *C*₁ is the usual input circuit tuned to the intermediate frequency, *W* the Westector, *R* the load resistance (of a much lower value than that used for thermionic diode detection), and *C*₂ is a reservoir condenser. The latter increases the output of the rectifier, but if its value is made too great it will by-pass some of the signal currents. Voltage variations along *R* due to the incoming carrier wave are applied to the grids of the controlled valves in the same way as when a thermionic valve is used for control, while the low frequency currents are led away to the L.F. amplifier via condenser *C*₃.

In Fig. 70 is seen an arrangement for obtaining full-wave rectification, using the metal rectifier in a similar circuit to that generally employed with a double thermionic diode. Two rectifiers

W_1 and W_2 have their positive terminals connected together and to earth, and the input coil is centre tapped. By means of the

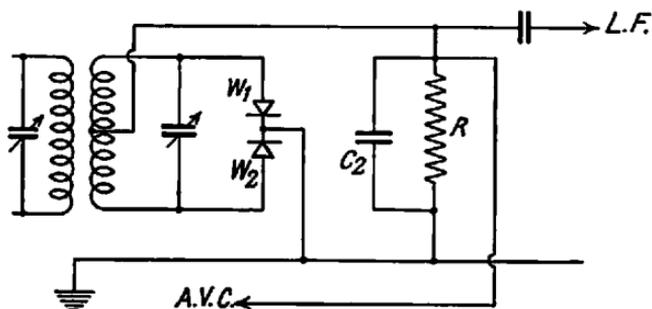


FIG. 70. FULL-WAVE METAL RECTIFIER AS A.V.C. DEVICE

latter connection, any residual intermediate frequency currents are cancelled out in the two halves of the input coil.

The metal rectifier can also be made to supply delayed A.V.C.

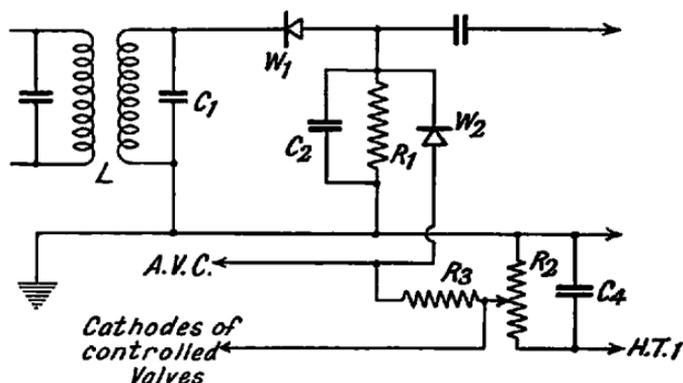


FIG. 71. DELAYED A.V.C. IS OBTAINED FROM THE CIRCUIT SHOWN ABOVE

A circuit for effecting this is shown in Fig. 71, in which W_2 is the control rectifier. Owing to the voltage drop down R_2 due to the flow of the full anode current of the receiver, there is applied to W_2 a polarizing potential depending upon the position of the variable contact point along R_2 . The value of this bias is adjusted to the desired degree of delay, so that no control bias is applied to the I.F. or H.F. valves until signals of a predetermined strength are being received.

There is a large variety of circuit arrangements in which the

Westector can be employed for A.V.C. purposes, including amplified, quiet and combined quiet, delayed, amplified A.V.C.

One further circuit that is of special interest, however, is the arrangement utilizing the last intermediate frequency stage as the first low frequency amplifier during reproduction from a gramophone pick-up. This is desirable in receivers fitted with only one L.F. stage, as the amplification obtainable in such instances is usually insufficient to give the output normally required for gramophone reproduction.

Visual Tuning. From the foregoing notes on automatic volume control it is clear that a signal cannot be tuned in by the usual method of adjusting the receiver to give the loudest reproduction from the loudspeaker, since a station can often be received at equal intensity over a comparatively wide section of the tuning dial. This tends to make a receiver fitted with A.V.C. appear less selective than one without it. It is important that the receiver be properly tuned, otherwise the quality of reproduction will suffer owing to the circuits passing certain frequencies in the sidebands more freely than others, resulting in notes in one portion of the musical register being amplified more than others.

To enable accurate tuning to be effected, some kind of visual tuning device is often included in a receiver equipped with A.V.C. There are various types of visual device, but those most commonly used consist of either a neon lamp or else a milliammeter connected into the anode circuit of a high frequency amplifier. As the tuning control is rotated and a station is tuned in, the bias applied to the controlled valves is gradually increased until, at the correct point, the bias is a maximum. The anode current must, therefore, be a minimum. This is the indication when a milliammeter is used for tuning.

Cosson Neon Tuning Indicator. This consists of a neon lamp with three electrodes, cathode, anode, and priming electrode. The cathode extends up the length of the glass tube, and the other electrodes are short and attached to one end. When 145-160 volts are applied between anode and cathode, a glow discharge takes place the length of which is dependent upon the actual voltage existing across these electrodes.

The circuit connections for this device are illustrated in Fig. 72. Anode *A* is joined to the controlled valve anode through a resistance *R1*. The latter is not always necessary and is only used if maximum glow takes place before the station is properly tuned in. Cathode *K* is connected to a point along resistance *R3* that will apply the requisite voltage across the neon lamp. In operation, the length of the glow between cathode and anode will vary according to the value of A.V.C. bias applied to the controlled valve to which the neon lamp is connected, for an increase in

grid bias reduces the anode current and consequently increases the voltage at the anode. The point of the tuning scale at which maximum length of glow is obtained is, therefore, the correct

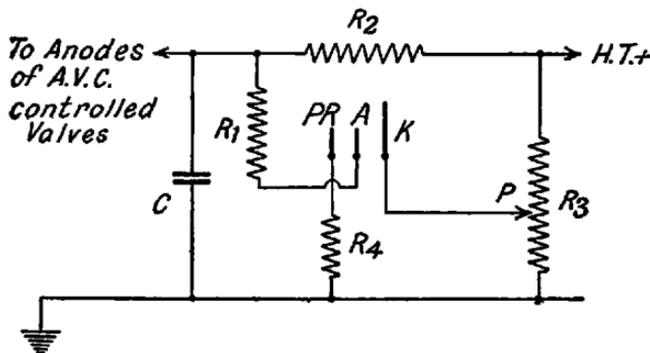


FIG. 72. THE THEORETICAL CONNECTIONS OF THE COSSOR NEON TUNING INDICATOR

tuning spot. About three milliamperes of current flow through the lamp at full glow.

To maintain slight ionization in the lamp a third electrode *PR* is inserted next to the anode. This is known as the primer.

Another visual tuning indicator is described in Chapter VII in connection with the Philco receiver employing shadow tuning.

CHAPTER VII

SOME MODERN SUPERHETERODYNE RECEIVERS

The Short-wave Converter. Reception of short-wave stations is becoming increasingly popular in Great Britain. This is due in great part to the large ranges that are easily obtained on the short wavelengths with even a small receiver.

A straight receiver is of limited use in short-wave reception owing to the very high signal frequencies that have to be amplified, and although satisfactory receivers of this type can be constructed, fewer difficulties are encountered if a superheterodyne with a comparatively low intermediate frequency is employed for the purpose. In order to convert an existing straight medium and long wavelength receiver to a short-wave receiver, a number of short-wave converters have been put on the market which, in effect, change a straight receiver into a superheterodyne. A converter consists essentially of an oscillator valve and circuit which acts as the local oscillation generator and first detector, while the normal receiver acts as intermediate frequency amplifier, second detector, and L.F. amplifier. A straight receiver, in order to perform these functions, must comprise at least one H.F. valve to take the part of I.F. amplifier during short-wave reception.

In actual operation, the receiver is adjusted to receive on the long waves—usually about 1000 metres, corresponding to a frequency of 300 kc/s. Although this is a high intermediate frequency in comparison to the standard frequency used by most superheterodyne receivers, it is found quite practicable for the purpose being considered. Amplification at 300 kc/s is certainly more reliably accomplished than at 20,000 kc/s, which is the frequency to which these converters are often capable of receiving.

A typical circuit of a short-wave converter is shown in Fig. 66. The aerial is connected to coil *L1* tuned by condenser *C1* to the oscillation frequency. Heterodyne voltages are generated by the usual feed-back method by means of coil *L2* connected to the anode, and the intensity of these oscillations is controlled by the reaction condenser *C3*. Grid leak *R* and condenser *C2* are to enable the valve to rectify the beat currents. Short-wave choke *Ch1* is to stop the local oscillations reaching the receiver, and H.F. choke *Ch2* is to act, in conjunction with *C4*, as the normal choke-capacity coupling for high frequency circuits.

When incoming signals are impressed on the input circuit via *L1* they are combined with the local oscillations to form beat currents,

which are rectified as in common superheterodyne practice and passed through to the aerial circuit of the straight receiver, and there take the place of a normal incoming signal. It is seen that the converter is an autodyne receiver, which has previously been described as being an inefficient type of receiver, owing to the high resistance of the oscillatory circuit to incoming signals when used for telephony reception on the 500 kc/s to 1000 kc/s band. This objection to autodyne reception, however, does not hold good at the very high frequencies for which a converter is designed, for the *percentage* mistuning—the factor governing the impedance

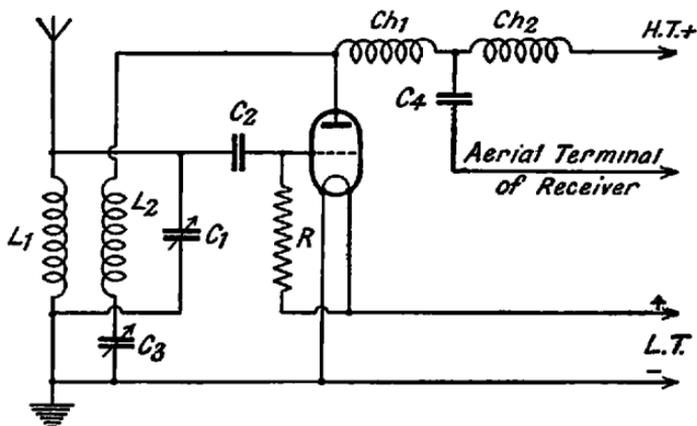


FIG. 73. CONVENTIONAL ARRANGEMENT FOR A SHORT-WAVE CONVERTER

of the circuit to incoming signals—will now be very small. For example, if a 1000 kc/s signal is being received, and the intermediate frequency is 150 kc/s, then the oscillation circuit, tuned to 1050 kc/s, will be $\frac{150}{1000} \times 100 = 15$ per cent off signal resonance, and the efficiency of the circuit for receiving the signals will be very low. Considering a short-wave case: if the I.F. is again 150 kc/s and the incoming signal this time has a frequency of 10,000 kc/s, then the oscillatory circuit will be only $\frac{150}{10,000} \times 100 = 1.5$ per cent off tune, which is not sufficient to cause too serious a loss.

Many variations of the circuit given in Fig. 73 are used in modern short-wave converters, but they are not of great interest in this outline, which is to show that the superheterodyne is capable of ready adaptation.

Pye Model T21. This receiver is a good example of the successful application of modern valves to produce a selective receiver capable of receiving distant stations, with such refinements as muting between stations and visual indication, employing only three receiver valves. Designed for working from A.C. mains, this model comprises a triode-pentode frequency changer, H.F. pentode intermediate frequency amplifier, and a double-diode-pentode as second detector, A.V.C. valve and output valve. Until the introduction of the high slope double-diode-pentodes of the type used in this receiver, it was usual in three-valve superheterodynes—or “short superhets” as they are commonly referred to—to couple the frequency changer to the second detector without utilizing an I.F. amplifier. The high gain now obtainable from both the frequency changer and the pentode section of the double-diode-pentode makes the employment of an I.F. amplifier possible, with consequently greatly improved adjacent channel selectivity as compared with the earlier models of short superhets.

From the circuit diagram of the Pye Model T21 shown in Fig. 74 it is seen that the aerial is coupled to the input of the pentode section of $V1$ through a band-pass filter consisting of coils $L1$ to $L3$, tuning condensers $C1$ and $C3$ with associated trimmers, and long wave coil trimmers $C2$ and $C4$. Inductive coupling is employed between the coils of the band-pass filter. Condenser $C5$ is the decoupling condenser used for A.V.C.

Oscillations are set up in the triode section by means of the coupling between anode coil $L6$ and the cathode injection coil $L7$ connected in the common cathode lead of both pentode and triode sections of the valve. These three coils have iron cores. The oscillator grid is joined to the cathode through grid leak $R1$ (100,000 ohms) and to earth via grid condenser $C6$ (0.0002 μF). Across the oscillator coil is connected a damping resistance, $R2$ of 40,000 ohms, to assist in the maintenance of a constant heterodyne voltage. The wave change switching is such that on long waves $C9$ is thrown into circuit in addition to the long wave (lower) section of $L6$. $C9$ is adjusted for correct tracking on the long waves. Alignment of oscillator and signal frequency circuits is obtained from specially shaped oscillator plates, and so padding condensers are not needed. The oscillator tuning condenser is $C11$. Grid bias for the pentode section of $V1$ is provided by the voltage drop down $R3$.

The intermediate frequency is 127 kc/s and both the I.F. transformers $L4$, $L5$ and $L8$, $L9$ have tuned windings and are coupled to form a band-pass filter. Coils $L12$, $L13$ and $L14$ are part of the visual indicator system and will be described later. $V2$ is connected in a straightforward manner for an I.F. amplifier,

and passes on the intermediate frequency signals to the signal diode *D1*. On the cathode side of this diode *L10*, *C14* and *C16* constitute a filter for the intermediate frequency, the former acting as a choke and the latter as by-pass condensers. *R5* is the signal diode load, and the L.F. impulses on it are passed via *C15* to the manual volume control *R6* (250,000 ohms), whence they are fed to the output pentode control grid. A resistance, *R9* of 25,000 ohms, is connected to the grid of the pentode to act as a stopper to any stray I.F. currents.

From the plate of the I.F. valve, voltages are passed to the A.V.C. diode *D2* through *C17*, and control voltages are set up along *R11* and *R12* for controlling the frequency changer through *R14* and *R15* and the I.F. valve through *R13*. Less control voltage is thus applied to *V2* than to *V1* since the lead to the grid of the former is tapped between *R12* and *R13*. Delayed operation of the A.V.C. is obtained by the voltage drop along *R7* and *R8* which makes the cathode of *V3* positive with respect to *D2* anode. The load resistance of *D1* (*R5*) is not joined to the cathode, but is taken to a point along the cathode resistors. Since the cathode itself is at a positive potential with respect to earth, due to the voltage drops along *R7* and *R8*, the anode of *D1* must, therefore, be NEGATIVE with respect to the cathode by the amount of drop down *R7*. This means that *D1* cannot detect the signals until the signal voltage input to it is greater than the negative bias applied to it by *R7*. A simple form of noise suppression between tuning points is thus obtained. Incidentally, *R7* forms also the bias resistance for the pentode section, since the grid return goes to the earth side of *R7*.

The pentode section of *V3* is connected in the usual manner, with *R10* and *C18* across the output transformer to act as tone corrector. Coil *L12* is for the purpose of balancing out any hum that may be present in the speech coil and is magnetically in circuit with the smoothing choke *L11* which is actually the speaker field winding. Electrolytic condensers *C19* (8 μ F) and *C20* (16 μ F) are the normal smoothing condensers for the rectified A.C. supply.

Returning now to the visual indicator already referred to in connection with the anode circuit of the pentode section of *V1*, it is seen that the indicator circuit comprises the series connection of the tuning lamp with iron-cored coils *L12* and *L14* in parallel. On the same core as these two coils, but situated between them, is *L13* connected in the plate feed circuit of the pentode of *V1*. The principle on which the indicator works is that the effective inductance of a coil is decreased as the magnetization of the iron core is increased, and that the choking effect on the current flow in the coil decreases correspondingly. In practice, this works

as follows: between tuning points, when, due to the working of the A.V.C., the sensitivity of the H.F. pentode is at maximum, the anode current flow through *L13* is greatest and sets up a high magnetization of the common iron core. This reduces the inductance of *L12* and *L13* and thereby their choking effect on the A.C. current (from the heater supply) in the lamp circuit, and so allows the maximum current to flow. When a station is tuned in, however, the anode current of *V1* becomes less, the magnetization of the core is reduced, the inductance of *L12* and *L14* is increased and the A.C. in the lamp circuit is choked back more effectively, bringing about a diminution in the brilliancy of the illumination of the lamp. The correct tuning point is thus indicated by minimum glow by the lamp.

Valves are employed in this receiver as follows—

V1, metallized triode-pentode AC/TP, Mazda.

V2, metallized H.F. pentode, AC/VP1, Mazda.

V3, double-diode-pentode, AC2/Pen DD, Mazda.

Mains rectifier, 1W3, Mullard.

Kolster-Brandes Model K-B 427. This is one of the "Rejectostat" receivers designed to operate in conjunction with the Kolster-Brandes system of eliminating electrical interference effects from radio receivers. The "Rejectostat" is an aerial fitting, and consequently is not shown in the diagram of this receiver. The circuit arrangement of the receiver comprises a heptode frequency changer, H.F. pentode as intermediate frequency amplifier, double diode as second detector and delayed A.V.C. valve, and a high slope output pentode valve. Variable selectivity is provided and the set is especially adapted for working with a short-wave converter, which may be left connected permanently with the main receiver.

In Fig. 75 is seen the circuit diagram. The aerial is coupled by means of an aperiodic aerial coil *L1* to a band-pass filter consisting of *L2*, *L3*, *L4* tuned by ganged variable condensers *C1* and *C2*. Coils *L2* and *L3* are not in inductive relation to each other but are coupled by coil *L4*. The lower ends of *L2* and *L3* are the long wave coils, controlled by short circuiting switches which throw simultaneously into circuit trimming condensers *C3*, *C4* for assisting the alignment of the circuits.

There are two reaction coils *L8*, *L9* in the oscillator anode circuit for feeding back oscillations to the oscillator grid circuit. For long wave reception the controlling switch is open and only *L8*, coupled to the long wave tuned oscillator coil *L7* is in circuit, but when the set is switched to medium waves, *L9* is joined in parallel to *L8* and brings about a reduction in total reaction.

On the tuned grid side of the oscillator valve section, *L7* is tuned by variable condenser *C9* and its trimmer. Alignment between signal frequency and oscillator circuits for medium wave reception is obtained by means of padding condenser *C10* and its trimmer *C11*. During reception on long waves, the switch in the tuned grid circuit is opened and connects, in addition to the long wave section of *L7*, a coil trimming condenser *C12* and an auxiliary padding trimmer *C13*. The usual grid condenser is seen at *C8* and grid leak at *R3*.

Intermediate frequency signals are taken from the output circuit of the heptode by transformer *L5 L6*, with a condenser trimmer to tune each winding to 130 kc/s, and produce a band-pass arrangement. *L6* is joined to the grid of the pentode I.F. amplifier in the usual manner, and amplified signals appear in the second I.F. transformer *L10 L11*, also with tuned primary and secondary windings. Signals in *L11* are applied to the signal diode *D1* directly and to the A.V.C. diode *D2* via condenser *C19* which in practice consists of a length of wire twisted round another of heavier gauge. The coupling between *L10* and *L11* is controlled by a knob on the receiver panel enabling a continuous variation of selectivity to be obtainable. At the point of greatest selectivity, *C16* (0.001 μ F), in the low potential lead of *L11*, is connected to earth by its switch, and this accentuates the apparent selectivity by increasing the sideband cutting.

The signal diode load is *R4* (500,000 ohms) and the I.F. by-pass condenser is *C17* (0.0005 μ F). Low frequency voltages pass through coupling condenser *C18* (0.01 μ F) and along the manual volume control *R5* (500,000 ohms) to be tapped off and applied to the control grid of the output pentode. Rectified voltages from the A.V.C. diode pass along *R7*, and are applied to the I.F. valve through *R6* and to the frequency changer through *R8*.

The circuit of *V4* is quite a usual one, with tone corrector consisting of *R9* and *C20*. A nine pin plug and socket fitting connects the mains unit to the receiver and at the same time supplies operating voltages to the short-wave converter socket.

Philco Model 98, Series 2. This is an American all-wave receiver employing six receiver valves and rectifier. In addition to long and medium waves, this model is designed to receive over the 2200/2600 kc/s, and the 5800/18,000 kc/s bands. The 2200/2600 kc/s band is employed in America for police communication. The circuit arrangement consists of H.F. amplifier (pentode), frequency changer (heptode), I.F. amplifier (pentode), second detection, L.F. amplification and A.V.C. (double-diode-triode), and an output stage consisting of two pentodes in push-pull capable of giving an output of about 7 watts. Overall

sensitivity is 5 microvolts and the second detector sensitivity is 0.43 volts.

In Fig. 76 is seen the complete circuit diagram of the Philco Model 98. This diagram has not been simplified, so that the switching arrangement for the various wavebands may be examined. Switches *S1* and *S2* control the primary and secondary windings of the aerial transformer. It will be noted that *L1 C1* constituting an acceptor circuit tuned to the intermediate frequency, are permanently in circuit, being connected directly across aerial/earth. Incoming signals of intermediate frequency are thus by-passed to earth before they can set up interference in the I.F. amplifier. This is a feature that is found in quite a number of British and Continental receivers.

The pre-set condensers shown connected across the secondary of the aerial transformer, are incorporated as part of that unit and are for alignment purposes. They are termed "compensating condensers" by the manufacturers of the set. One winding is shared by the police (2200/2600 kc/s) and medium wave-band, although it is seen from the arrangement of *S2* that only one-half of the winding is used at a time. Condenser *C12* is not part of the tuning arrangement but is merely the usual decoupling condenser (0.05 μ F capacity) employed for A.V.C. Switches *S2*, *S3* and *S4* each have a short circuiting strip, shown as a broken line, to eliminate any trouble due to the unused turns or "dead ends" on the tuning coils. This is of the utmost importance in all-wave receivers, as it is found that the presence of dead ends is liable to complicate the action of the receiver very considerably due to absorption effects at the resonance frequency of the unused turns. Coil *L2* is for the purpose of obtaining a small capacitive coupling. Variable condenser *C2* tunes the respective aerial transformer secondary winding.

High frequency pentode *V1* is coupled by means of coil assembly No. 2 to the frequency changer *V2*. There are two aperiodic primaries and four secondaries, each with trimming condenser, which are tuned by variable condenser *C3*. Coil *L3* serves a similar purpose to *L2*.

Coil assembly No. 3 forms the coupling arrangement for the oscillator section of the heptode *V2*. One reaction coil in the oscillator anode circuit is coupled to three separately trimmed secondaries in the oscillator grid circuit, the latter being tuned to the oscillator frequency by *C4*. One coil is used for both medium wave and police bands.

The oscillator grid return is taken to the cathode of *V2* directly, so that the grid is not biased by the voltage drop down *R2*, which is, therefore, only effective for the signal grid. This arrangement ensures that the grid is maintained at a constant potential

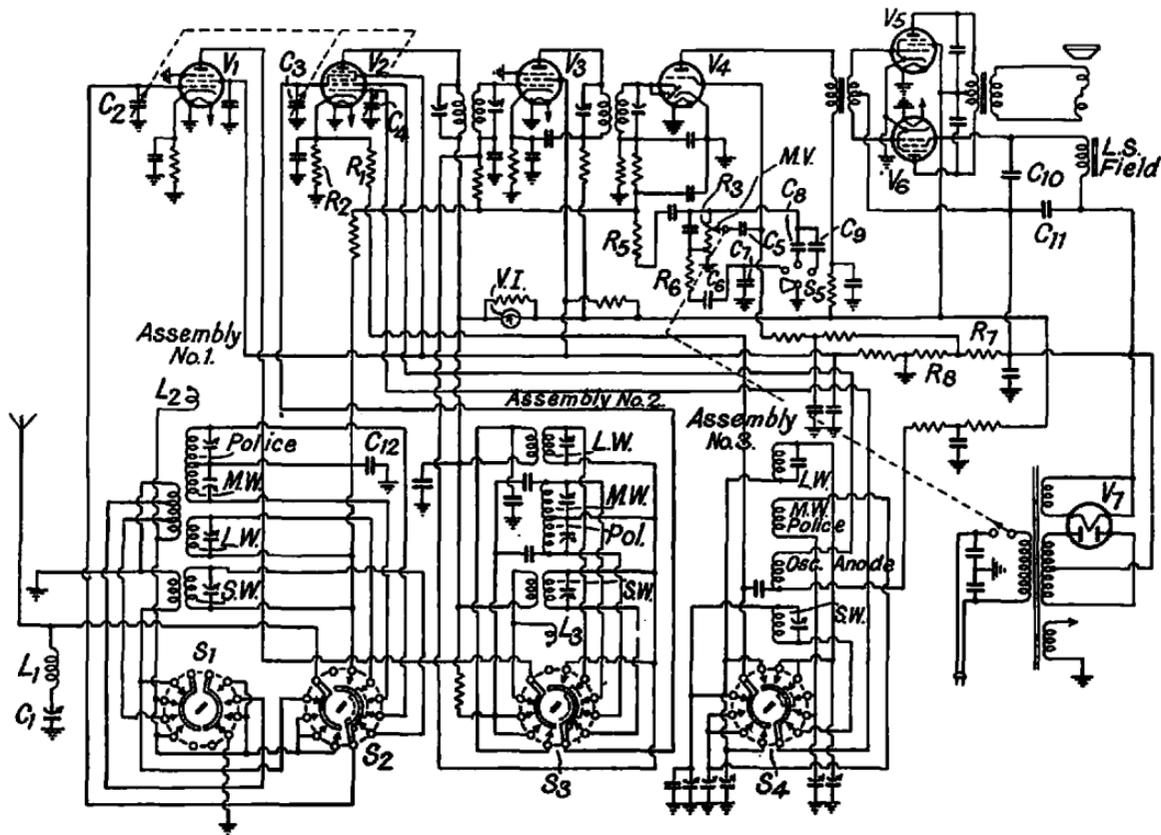


FIG. 76. CIRCUIT ARRANGEMENT OF THE PHILCO RECEIVER
Model 98, Series 2

with respect to the cathode, regardless of the fluctuations in main anode current. A negative voltage is, nevertheless, produced on the oscillator grid by the presence of $R1$ (51,000 ohms) at the low potential end of the grid circuit, by the flow of grid current during the periods that the grid is at a positive potential.

The frequency changer is coupled to the I.F. valve by an iron-cored transformer with primary and secondary tuned to 460 kc/s. A usual circuit is employed for the I.F. valve, the output transformer being iron cored also. Overall gain in this stage is 90. Second detection is performed by the two diodes of $V4$, the anodes of which are connected together and thus present half the impedance of a single diode for half-wave rectification. Automatic volume control voltage is also produced by the double diodes, and this is taken from the top of $R2$ to the control grids of $V1$, $V2$ and $V3$.

Low frequency voltages in the potentiometer resistance $R3$ (1 megohm) are tapped off by the manual volume control device MV and applied via coupling condenser $C5$ ($0.01 \mu F$) to the grid of $V4$. Across the volume control is connected the tone control device, consisting of $C7$, $C8$ and $C9$ and short circuiting switch $S5$. When $S5$ is at its bottom left-hand position, as shown, $C6$ ($0.015 \mu F$) is joined in series with $R8$ and $C7$. As the switch is rotated in a clockwise direction, first $C7$ is short circuited by the switch blade connected to earth, second $C8$ ($0.007 \mu F$) is connected across the volume control, and in the last position, for deepest tone, $C9$ ($0.02 \mu F$) is thrown across the load. Transformer coupling is employed between $V4$ and the push-pull output stage, giving the large output already mentioned.

The smoothing system consists of the loudspeaker field and condensers $C10$ ($8 \mu F$) and $C11$ ($12 \mu F$), and the full voltage of the mains unit is applied to screen and anode of the push-pull pentodes. Across the mains transformer primary are connected two condensers of $0.015 \mu F$ capacity with their centre connection earthed. These condensers act as a filter for mains noises and also as a means of preventing modulation hum.

A visual indicator is connected in the anode circuit of $V2$, indicated by VI . This device is known as a shadow tuning indicator, and it works as follows. A coil of wire in the anode circuit of $V2$ acts as an electromagnet, the strength of which is dependent upon the anode current flow. Within the coil a rotatable piece of soft iron is fitted and carries a light arm with a window. Across the centre of the window is an opaque strip. A light source is arranged on one side of the window, the tuning indicator screen in the receiver cabinet being in a straight line on the other side. The relative distances between window, opaque strip and light source are so adjusted that when maximum current

passes round the coil (the condition for zero signal input) the soft iron is rotated into a position that places the opaque strip near the light source, and thus produces a broad shadow on the screen. When a strong signal is being received, however, the anode current is reduced (due to the A.V.C. bias), and the strip is moved away from the light. The shadow on the screen is, therefore, narrowed to an extent depending upon the strength of the incoming signal and the accuracy of the tuning. The correct tuning position is that in which the shadow is narrowest for the particular station.

The G.E.C. Car Radio Receiver. This receiver employs five receiver valves arranged as H.F. amplifier, frequency changer, I.F. amplifier, combined second detector, A.V.C. valve and L.F. amplification, and output valve, the particular types being H.F. pentode, heptode, H.F. pentode, double-diode-triode and power pentode respectively. Power supply is obtained from a rotary transformer which is fed by the 12-volt car accumulator. The five 13-volt heaters are connected in parallel.

In Fig. 77 is seen the complete diagram of the receiver. The aerial is coupled to a simple tuned input circuit connected to the H.F. pentode $V1$. It should be noted that adjacent channel selectivity is not a major problem with car radio receivers owing to the comparatively poor pick-up of the aerial which itself constitutes a highly-selective device. Consequently, a single tuned circuit between the aerial and $V1$ is found to be sufficiently selective. A sensitivity control is fitted, and consists of $R1$ and a switch. The resistance is, in effect, parallel to the grid bias resistance $R10$ of $V1$, with the result that when the sensitivity control switch is closed, the total bias resistance is greatly reduced and $V1$ is much more sensitive to weak signals. During reception of loud signals, however, the effect of closing the sensitivity switch is not appreciable owing to the working of the A.V.C. system which applies a high bias to $V1$. In practice, $V1$ is worked in its less sensitive state (sensitivity switch open) while the motor-car engine is running, as the noise level due to ignition interference is then much lower. Maximum sensitivity may be employed with advantage for weak signals, however, while the engine is not running.

The untuned coil in the anode circuit of $V1$ is inductively and capacitively coupled to the tuned input grid circuit of the heptode $V2$. The oscillator section of this valve is back coupled in the usual way and the grid leak $R2$ (99,000 ohms) is connected directly to the cathode so that the grid shall not receive any bias voltage developed by the bias resistor $R3$ for the input grid. Padding condensers are employed for ganging the oscillator

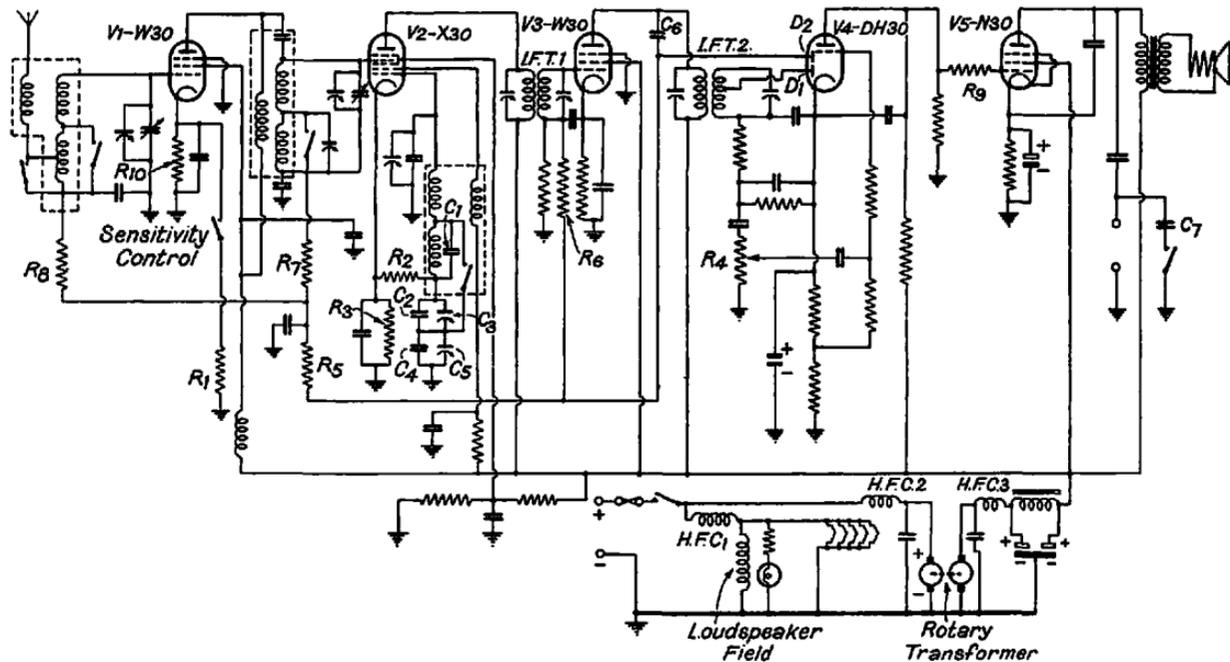


FIG. 77. G.E.C. CAR RADIO RECEIVER

to the signal frequency circuits. The long wave padder is C_2 in series with C_4 , and the medium wave padder is C_4 with its trimmer C_5 . Condenser C_1 is connected permanently across the long wave coil to assist the alignment on the longer waveband.

Heptode V_2 is coupled to the intermediate frequency amplifier valve V_3 by the usual transformer with tuned primary and secondary. The intermediate frequency is 125 kc/s. Another tuned I.F. transformer couples the output of V_3 to the signal diode D_1 of double-diode-triode V_4 , while the A.V.C. diode D_2 is connected to the anode of V_3 through condenser C_6 . Rectified signals pass from the circuit of D_1 along to R_4 (500,000 ohms) and are tapped off and applied to the grid of the triode section of V_4 . R_4 therefore constitutes a manual volume control.

The voltage developed across R_5 by the A.V.C. diode D_2 is applied to the respective grids of V_3 through R_6 (500,000 ohms), V_2 through R_7 (99,000 ohms) and V_1 through R_8 (99,000 ohms), so that actually three valves are automatically controlled. This ensures a large measure of constancy in output signal intensity to compensate for the large input voltage fluctuations while the car is travelling.

Resistance coupling is, as usual, employed between the triode section of V_4 , and the input circuit of output pentode V_5 . The resistance R_9 inserted in the grid circuit of V_5 is for the purpose of stopping any stray currents of intermediate frequency that happen to have penetrated into this part of the circuit.

The output valve is connected in the standard manner. Some measure of tone control is obtained by means of condenser C_7 (0.02 μ F) which may be switched across the pentode.

High tension voltage is generated by the rotary transformer driven by the 12 volt car accumulator battery. On the H.T. side, the rotary transformer develops 265 volts unsmoothed, and when the receiver is at maximum sensitivity 240 volts are available for the valve anodes. It will be noticed that the normal smoothing circuit of series inductance and shunt condensers is employed to smooth the H.T. supply. The 13-volt valve heaters are connected in parallel across the accumulator battery and loudspeaker field. The total current consumption of the heaters is 1.5 amperes and the loudspeaker field requires 0.4 ampere. High frequency filters are connected in heater and rotary transformer L.T. and H.T. circuits for the purpose of diminishing the interference that is liable to be produced due to the L.T. leads acting as small aerials and picking up the engine-generated noises.

Osram valves are employed in this receiver as follows—

V_1 , W30; V_2 , X30; V_3 , W30; V_4 , DH30; V_5 , N30.

The "Wireless World" Single-span Receiver. A recent design of

superheterodyne receiver that has been developed by the *Wireless World* enables the entire broadcast bands of frequencies to be covered by a single span of the tuning condenser dial—hence its name, the “single-span receiver.”

In this receiver the aerial circuit takes the form of a two-stage band-pass filter. This filter is designed to pass signals of frequencies below the highest in the broadcast bands, but to suppress signals of frequencies above this value. No tuning is required at this part of the receiver, as the filter is for the purpose of impressing *all* broadcast signal voltages of frequencies below the limit mentioned above on to the control grid of the first valve. In other words, the signal frequency circuits, usually an integral part of the superheterodyne receiver, are replaced by a filter.

The effect of this is to overcome one of the major problems associated with the working of a superheterodyne receiver—the ganging of the oscillator and the signal frequency circuits. As there are no circuits tuned to the signal frequency, there is obviously nothing to which the oscillator tuning condenser has to be aligned. The latter is, therefore, the only tuning element in the receiver.

In addition to avoiding the difficulties usually concerned with ganged condensers, the single-span receiver also overcomes the necessity to employ long and short wave coils with their attendant switching devices. This not only cheapens the construction of the receiver, but also gets rid of a source of trouble.

In order to cover the two broadcast bands of frequencies with one span of the oscillator condenser, a high intermediate frequency is used. By this means, the ratio of maximum to minimum frequencies to which the system has to be tunable is brought well within the useful range of a small coil and variable condenser. The intermediate frequency used is 1600 kc/s. As the broadcast bands to be covered extend from 150 kc/s to 1500 kc/s, the oscillator circuit has to tune from 1750 kc/s to 3100 kc/s. This variation is easily accomplished by a 0.00016 μ F condenser.

One advantage of using an intermediate frequency of 1600 kc/s is that the second channel signals will be well separated from the desired signal, and will thus be eliminated more easily from the amplifier. The actual range of second channel frequencies will be from 3350 kc/s (i.e. the lowest frequency of the oscillator 1750 kc/s + the intermediate frequency 1600 kc/s) to 4700 kc/s (3100 kc/s + 1600 kc/s). It has already been mentioned that the input filter is designed to suppress signals above the highest in the broadcast bands. By this means, second channel interference is eradicated, for from the figures given above it is seen that the lowest second channel frequency is higher than the highest desired signal frequency.

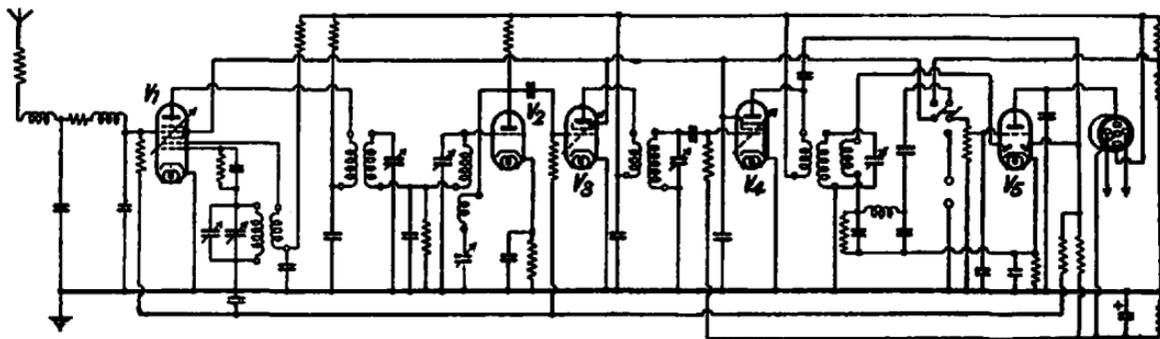


FIG. 78. "THE WIRELESS WORLD" SINGLE SPAN RECEIVER CIRCUIT

A drawback to the use of such a high intermediate frequency is that the selective qualities of the low intermediate frequency circuits usually employed in a superheterodyne receiver are lost. To compensate for this, four circuits tuned to the intermediate frequency are used, and there is the selectivity control.

The above are the outstanding features of the single-span receiver. Other points of interest will be evident from an examination of the circuit diagram given in Fig. 78.

The aerial is connected to a capacity coupled band-pass filter, which applies signal voltages to the control grid of a pentagrid. The oscillator portion of the pentagrid is connected in the usual way. It should be appreciated that signals of all broadcast frequencies are impressed upon the control grid of the tetrode portion. The desired incoming signal is selected by means of the heterodyne oscillations, which beat with it and cause the required frequency to be passed to the intermediate frequency amplifier via the pentagrid anode coil.

From the output coil of the pentagrid valve the desired signal passes over a filter tuned to 1600 kc/s to a buffer or reactor valve V2. This valve is for the purpose of applying negative resistance to the intermediate frequency filter by means of the reaction coil in its anode circuit. By increasing the reaction control capacity in series with the reaction coil, the desired signal tends to increase in intensity. Since, however, A.V.C. is employed, the net result is a constant signal intensity but improved selectivity. Although a certain amount of sideband cutting takes place in the position of maximum selectivity, this can be avoided during reception of a local station or strong signal, when no reaction is normally necessary.

Resistance-capacity coupling is employed between the reactor valve and the first intermediate frequency valve V3, which is a variable μ screen-grid valve. The anode coil of V3 is coupled to another I.F. tuned circuit connected to the grid of a high frequency pentode V4.

The anode coil of V4 is coupled to a circuit tuned to the intermediate frequency, this tuned circuit being in turn coupled to a third winding which applies the desired signal voltages to one of the diode anodes. This arrangement enables a step-down ratio to be obtained, and thus to increase selectivity by reducing damping, and at the same time minimizes the H.F. potentials applied to the load resistance of the detector anode.

A.V.C. voltages are obtained from the second diode of the double-diode-triode, which is connected to the anode circuit of V4 through a condenser. These voltages are applied to V1 and V3.

Valves used in this receiver are as follows—

- V1 Ferranti *VHT4*. V2 Osram or Marconi *ML4*.
 V3 Osram or Marconi *VMS4*. V4, Ferranti *VPT4*.
 V5 Osram or Marconi *MHD4*.

Telefunken Bayreuth Superheterodyne. This model is one of the most up-to-date receivers in Germany, and is representative of the superheterodynes manufactured by the Telefunken Company. The five valves used are, with the exception of the output pentode, unusual in Britain. *Fading hexodes*—so called because they have variable μ characteristics and can, therefore, be used for reducing the effects of fading—are employed as signal frequency and intermediate frequency amplifiers. A *mixing hexode*, which derives its name from the fact that it mixes the incoming signal with the heterodyne voltages by its electron stream, acts as detector-oscillator. A screen-grid binode or diode-triode acts as second detector. This valve is a combined diode and triode, and is used for the duties of rectification, A.V.C., and L.F. amplification. The receiver, which has an overall gain of ten million, incorporates a variable noise suppressor and shadow tuning device.

The theoretical diagram of the D.C. version of this receiver is given in Fig. 79. The aerial is inductively coupled to the input circuit of the first fading hexode V1, and across the aerial windings of the coupling coil an acceptor or low resistance resonance circuit is connected. This acceptor circuit is tuned to the intermediate frequency, with the result that any voltages impressed on the aerial coil at that frequency are by-passed directly to earth instead of breaking through into the I.F. circuits and causing interference.

From the output of V1 the amplified signal passes to the input of mixing hexode V2, and is combined in the electron stream with the local oscillations generated by feed-back between the third and fourth grids. This circuit differs from the one shown in Chapter V, in that the signal frequency circuit is connected to the grid nearest the cathode instead of to the one nearest the anode. The effect on the output is the same, however, for after the two sets of high frequency voltages have been combined by the common cathode stream, the beats are rectified by adjusting the operating voltages to cause the valve to function as an anode bend detector.

Intermediate frequency amplification is effected at 132 kc/s by the second fading hexode V3. Two pairs of tuned circuits are employed in this stage, and they are adjusted to give a band-pass filter effect. A variable bias is applied to V3 by means of the resistance in the cathode load for background noise suppression.

Amplified I.F. signals are applied to the binode which effects

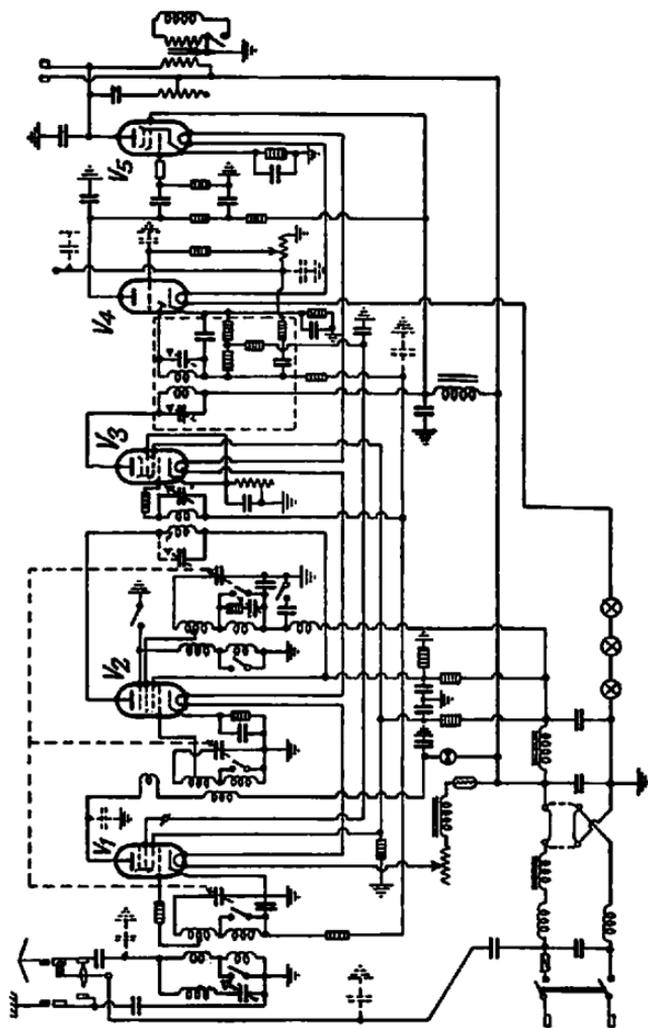


FIG. 79. CIRCUIT OF THE TELEFUNKEN BAYREUTH D.C. SUPERHETERODYNE

distortionless rectification, and at the same time provides A.V.C. voltages for the two fading hexodes. The A.V.C. device will maintain a constant signal output through input voltage variations in the ratio of 1 to 300,000. Audio frequency voltages are applied to the grid of the triode portion of V_4 by a potentiometer, which acts as manual volume control.

Resistance coupling is employed between V_4 and the output valve, a power pentode. The arrangement of the latter is quite a usual one, with a tone control across the primary of the output transformer.

Marcophonophone Portable Superhet, Model 269. This receiver, being of the portable type, has its valves supplied by batteries. It is arranged to work with two frame aerials (built into the set itself, of course), and boasts the luxury, for a portable receiver, of A.V.C. This is provided by one of a pair of metal rectifiers, the other being used for second detection. Although only six thermionic valves are employed in the set, the actual function of the circuit is similar to one using seven valves; or, at least, to a six-valve receiver employing a double-diode-triode as second detector.

The circuit diagram is seen in Fig. 80. Frame aerial No. 2 is controlled by switch S_1 which either—

1. Short-circuits it entirely, leaving only frame aerial No. 1 operative, for medium wave reception;
2. Throws it in series with No. 1 frame, for long wave signals; or
3. Connects a grid bias tapping to the grid of valve V_1 . The bias voltage is sufficient to cut off the anode current of this valve, and so render the purely radio side of the receiver unworkable.

Terminals A and E are for connecting an external aerial and earth should these be desirable, such as in districts that are unfavourable to reception.

Selectivity with this kind of receiver does not demand the use of band-pass filters, owing to the assistance in this respect afforded by the directive effect of the frame aerials. Furthermore, the use of V_1 as a signal frequency amplifier results in an improved preselection, and greatly reduces the risk of second channel and other interference. This fact explains the use of a simple tuned circuit between V_1 and the screen-grid valve frequency changer V_2 .

The circuit for converting the signal frequency to the intermediate frequency comprises cathode injection of the back-coupled oscillatory voltage, and series connection of the oscillator circuit and tuned I.F. transformer primary. For correct alignment of the oscillator and preselector circuits, a padding condenser is employed.

Intermediate frequency amplification is carried out in valve V_3 , the anode circuit of which is coupled by a tuned I.F. transformer

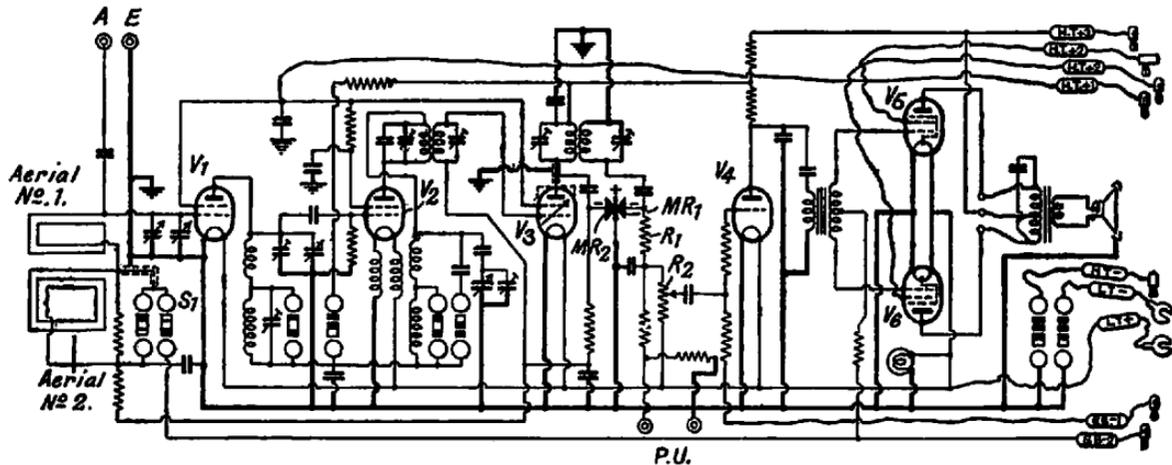


FIG. 80. THIS SHOWS THE THEORETICAL ARRANGEMENT OF THE MARCONIPHONE SUPERHETERODYNE MODEL 269

to a metal rectifier *MR1* acting as second detector. Rectified signal currents flow from *MR1* through the resistance *R1* and *R2*, and are tapped off the latter by an adjustable slider working as manual volume control. These signal voltages are then applied to the low frequency valve *V4*, which is the driver for two pentodes *V5* and *V6* functioning in a special arrangement known as the *parallel conductance principle*, and providing an undistorted output of $1\frac{1}{2}$ watts. In practice, this arrangement works in a similar manner to a quiescent push-pull amplifier, but gives better quality of reproduction owing to the valves being balanced individually. It will be noticed that common grid bias and anode voltage tappings are used for the two valves, but that the screen-grid voltage tappings are separate.

Metal rectifier *MR2* provides the control voltage for the delayed A.V.C. which is applied to the signal frequency amplifier and to the I.F. amplifier, but not to the frequency changer.

The anode current consumption of this receiver is very low considering six thermionic valves are in service, and averages eight to nine milliamperes. This desirable feature for a portable receiver is due to the special arrangement of the output valves and to the use of A.V.C.

Marconi thermionic valves are employed throughout, and are of the following types—

V1, screen-grid *S21* metallized; *V2*, screen-grid *S21*; *V3*, variable μ screen-grid, *VS2* metallized; *V4*, general purpose, *HL2* metallized; *V5* and *V6*, pentodes *PT2*.

R.G.D. Supersonic Radio-gramophone, Model 1201 A.C. This is one of the most expensive receivers manufactured in this country and embodies the most modern improvements that enhance the quality of reproduction or ease of operation. These include visual tuning; quiet, delayed and amplified A.V.C., I.F. stage coupled by band-pass filter, the entire I.F. coupling arrangement comprising six tuned circuits; a special output circuit known as a *paraphase push-pull* amplifier, designed to provide an exceptionally high tonal quality of reproduction; and a pair of matched loudspeakers. Eleven valves are employed in the receiver apart from the mains rectifier.

Referring to Fig. 81, valve *V1*, a variable μ screen-grid valve, acts as a signal frequency amplifier, the input circuit of which is a normal tuned circuit. This valve is coupled by an inductively coupled band-pass filter to valve *V2*, which works as an anode bend detector due to the bias applied to the grid as a result of the voltage drop down *R1*. In the anode circuit of the signal frequency amplifier is the tuning indicator which is operated by the anode current. As A.V.C. voltages are applied to the grid of this valve, the condition for accurate tuning will be minimum current.

The separate oscillator valve V_3 has a tuned circuit across the anode/cathode path, and a grid condenser and leak are used for stabilizing the oscillator voltage induced into the cathode coil of the mixer valve V_2 . It will be noted that the oscillator grid leak consists of two resistances, one being controlled by a switch. For reception on the medium waveband only, R_2 (value 2000 ohms)

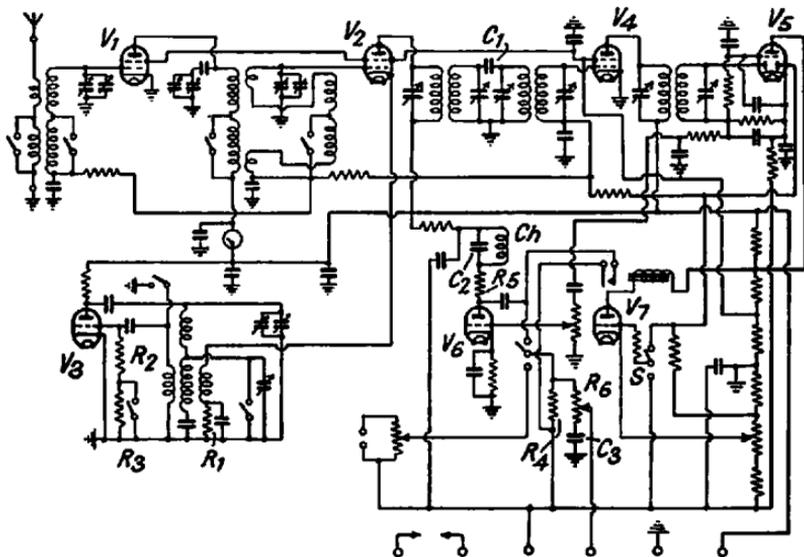


FIG. 81. CIRCUIT DIAGRAM OF THE R.G.D. RECEIVER MODEL 1201 A.C. WITHOUT THE L.F. PORTION

is used, R_3 then being short-circuited, while for long wave reception both R_2 and R_3 (40,000 ohms) are used. This arrangement ensures a close approach to the optimum heterodyne voltage induced in the first detector cathode coil on both wavebands.

The intermediate frequency coupling between the first detector and the single I.F. amplifier valve V_4 , is effected over a band-pass filter comprising four tuned circuits, while between the I.F. stage and the second detector V_5 a further two tuned circuits are employed at the intermediate frequency, making six in all. This arrangement is to enable an exceptional degree of selectivity to be obtained while at the same time to avoid side-band cutting. The intermediate band-pass filter between the first detector anode circuit and the I.F. amplifier input circuit is electrostatically coupled by condenser C_1 .

Double-diode-triode valve V_5 serves the purpose of detecting

the I.F. input, producing delayed A.V.C. voltages, and amplifying the latter. These actions are carried out by the two diodes and the triode portion respectively. A.V.C. voltages are applied to the signal frequency amplifier, first detector, I.F. amplifier, and Q.A.V.C. valve.

Quiet A.V.C. or noise suppression is effected by a separate valve *V7*. The input to this valve is obtained from the normal A.V.C. voltages, and the relay shown in the anode circuit is so adjusted that, with A.V.C. bias below any predetermined value, its contacts are closed and the grid lead *R4* of the L.F. output amplifier is short-circuited and the amplifier does not operate. When a signal of the desired strength is being received, the A.V.C. bias applied to *V7* will be sufficient to so reduce the current flowing in its anode circuit that the magnetizing force in the relay will be diminished to the point at which the contacts are released. The short circuit on the L.F. grid leak is thus broken, and the output amplifier is allowed to function. By suitable adjustment of the relay, a listener is enabled to hear signals of any intensity he may desire from weak ones to only the very strongest. If a very weak signal is desired to be received, the Q.A.V.C. valve *V7* may be cut out of circuit by connecting switch *S* to the earthed contact, so that its grid is earthed.

Valve *V6* is the first L.F. amplifier and acts as driver to the paraphase output stage. In the anode circuit of this valve is a tone correction circuit consisting of resistance *R5* in series with choke coil *Ch* and condenser *C2* in parallel. The function of this arrangement, which compensates for any sideband cutting that may have occurred during the signal's passage through the receiver, is discussed in Chapter IV. A manual tone control comprises potentiometer *R6* (500,000 ohms) and condenser *C3* (0.0001 μ F) in series with each other, but in parallel with the grid leak of the paraphase amplifier.

The circuit of the output stage is illustrated in Fig. 82, and consists of valves *V8*, *V9*, *V10*, and *V11* connected in an arrangement known as paraphase push-pull. A paraphase amplifier is one in which the voltages to be amplified are applied in opposite phase to the output valves by means of resistance-capacity coupling. It is a means for obtaining the advantages of high quality push-pull power amplification without resorting to transformer input coupling with its attendant risk of distortion.

The method of working of this type of amplifier can be seen from the figure. Signal voltages from the first L.F. valve are applied to the grid of *V8*. Low frequency voltages from the anode circuit of this valve are applied, via *C4*, *R7*, *R8*, and *C5* to the grid of *V9*. Now the voltages obtained from the anode circuit of *V8* will be in opposite phase to the input to that valve and, by suitable

adjustment of potentiometer *R8*, they can be made equal in intensity. The voltages on the grid of *V9* will, therefore, be opposite in phase but equal in strength to the potential input of *V8*, and, as this is the condition for push-pull amplification, the advantages of the latter system will be gained by an amplifier of this description. All the valves are worked on the straight part of their characteristics.

Magnified voltages in the anode circuits of *V8* and *V9* are applied in opposite phase by the usual resistance-capacity coupling

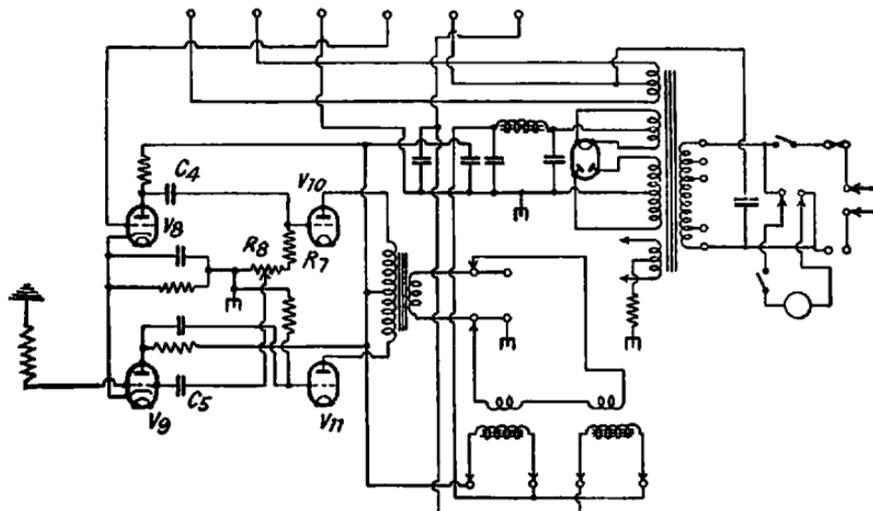


FIG. 82. CIRCUIT OF THE PARAPHASE PUSH-PULL OUTPUT AMPLIFIER OF THE R.G.D. RECEIVER MODEL 1201 A.C.

to the output valves *V10* and *V11*, in the common anode circuit of which a normal push-pull centre-tapped output transformer supplies the signal currents to the loudspeaker.

The valves used in this receiver are the following—

- V1* and *V4* Osram *VMS43*; *V2* Osram *VMS4*.
V3 Osram *MHL4*; *V5* Mazda *ACHL/DD*.
V6 Osram *MH4*; *V8* Cossor 4 *IMH*.
V8 and *V9* Mazda *AC/HL*; *V10* and *V11* Mazda *PP3/250*.

Marconi Diversity Telegraph Receiver, Type R.C. 47a. This chapter on examples of modern designs of superheterodyne receivers would not be complete without mention of a commercial type used for telegraphic communication across continents, and

developed by Marconi's Wireless Telegraph Co., Ltd. A receiver of this nature has to be relied upon to give a good service whenever called upon, and for recording purposes must have an overall amplification enormously greater than that obtainable in any type of broadcast receiver. It is not to be wondered at, therefore, if the steps taken by the Marconi Company's designers to ensure a constant and interference-free output, which shall be ample at all times to operate the recording mechanism for even the weakest desired signal, are radically different from the usual measures employed by broadcast receiver designers, and that twenty-five valves are employed instead of the usual five or six.

A diversity receiver is one arranged to amplify and reproduce signal voltages induced in two or more aerials situated in different localities. This method of reception is employed to overcome the effects of fading, for it is found that when signals received on one aerial tend to fade away, signals at another aerial situated a distance equal to several wavelengths away may be quite normal. When two aerials and receivers are connected to a recorder, therefore, the fades will tend to compensate each other and a much more reliable service can be maintained.

To equip two aerials with separate receivers and recorders would be very expensive, however, and means had to be taken to enable a common receiver to be used with two aerials. It was found to be quite impracticable to apply the two aerial inputs to a common circuit, owing to the difference in phase of the two signals. Unless the two sets of high frequency currents were in phase, loss of voltage would result, for the same phenomenon would take place as when a locally generated oscillation is combined with an incoming signal; that is to say, the resultant energy from the addition of the two currents would vary from zero to the sum of the two individual amplitudes. As the frequency of the two signal currents is the same, it is easy to see that by combining them irrespective of their phase, it is possible to have a small output, this being the effect of a deep fade, whereas the separate signal input from either may be quite sufficient to produce a loud signal.

This difficulty has been overcome by a device that switches the aerials into circuit alternately at a fairly rapid rate, so that at any time voltages from one aerial only actuate the receiver. A triode oscillator is used for this purpose, and it is arranged to generate a tone of 300, 500, or 700 cycles per second. A voltage at one of these frequencies is induced into the two signal frequency amplifiers associated with the two aerial circuits, so that while the grid of one amplifier valve has a positive bias applied to it, the grid of the other amplifier valve has a negative bias applied. The result of this is that one amplifier is rendered inoperative as

the other is enabled to function and *vice versa*, the alternation taking place at one of the tone frequencies mentioned above.

The signal frequency amplifier consists of three S.G. stages connected to each aerial, with a variable coupling between the tuned feeder circuit and the first valve input circuit. A variable coupling of this description has been found of great assistance during reception under bad atmospheric conditions, for by adjusting it the optimum coupling for the best signal to noise ratio can be effected.

In order to obtain a very high overall amplification, intermediate frequency amplification is effected at two different frequencies. The first intermediate amplification takes place at a mid-frequency of 300 kc/s. This frequency enables satisfactory freedom from image frequencies to be obtained, and at the same time it is not so high as to prohibit the construction of a stable and powerful amplifier. The latter comprises three auto-transformer coupled valves, and one alternator stage for controlling the gain of the first intermediate frequency amplifier in small steps.

For the second intermediate frequency amplifier a mid-frequency of 48 kc/s is used. Four band-filter triode stages supply energy to the third rectifier, consisting of a pair of valves connected in push-pull. Each of these four amplifier valves has a separate grid bias control on the main panel.

<i>Circuit</i>	<i>Valves</i>
Signal frequency amplifier	4
Switching oscillator	1
First intermediate frequency amplifier	4
Second intermediate frequency amplifier	4
First and second heterodynes	2
Three detector stages	4
Listening point	1
Tone sender	5
Total	25

In addition to the above there is a listening point using one valve. Alternatively, with the tone sender can be connected a D.C. bridge employing four valves.

The number of valves in this receiver is thus seen to be as given above.

All the sections can be easily withdrawn from the back of the panel for examination, as the component parts of each section are mounted on a separate insulated chassis especially for this purpose. The panel has a height of 6 feet 4 inches and a width of 3 feet 4 inches, while the depth of the section is 18 inches.

CHAPTER VIII

MAINTENANCE OF SUPERHETERODYNE RECEIVERS

THE following notes are not intended to be in any degree a treatise on the servicing of superheterodyne receivers. They are included in this book with the object of offering some guidance to those who wish to remedy the more simple faults that occur in even the best of receivers. Many of the tests can be carried out with a high resistance voltmeter or a milliammeter only, and in most cases it will be found possible to track the defect without the use of any other testing means than these instruments. For serious fault tracing it will often be necessary to employ a modulated oscillator and an output meter.

The first thing to do when a faulty receiver is examined is to take voltage readings at a number of "key" points. Most service manuals give the values of voltage to be obtained at various points, but for those readers who have made their own receiver, the most important voltage readings for a typical five valve receiver and power rectifier are set out on page 146. The amateur is advised to take the actual voltage readings while the receiver is in good working condition and to note them down for reference in the manner given. These voltages should be taken with volume control at maximum when no signals are being received, so as to avoid complications due to the working of the A.V.C. system.

It should be noted that the heater voltage is A.C. and will not be measurable with the ordinary D.C. voltmeter. When universal or D.C. valves are employed with D.C. mains, the heater voltage is D.C. and can be tested with the usual D.C. voltmeter.

Other very useful data that may profitably be tabulated with the information above, consists of the corresponding anode and screen grid currents. These are not read so easily, but they serve as a useful check on the condition of the respective valves as will be seen later.

The voltages in the list overpage cover the most important points in the receiver so far as the power supply is concerned and if anything is wrong with a valve or the supply voltage it will generally be shown up by one or more readings. An excessive voltage or reduced voltage reading enables the actual fault to be localized and is a big step in tracing it. For example, no voltage reading across the loudspeaker field winding (used as a smoothing choke) shows that no anode current is passing through the receiver. The next test should be between chassis and each

TEST VOLTAGES

	Chassis to Control Grid	Chassis to Cathode	Chassis to Anode	Chassis to Screen Grid
H.F. amplifier (Screened pentode)	- 0.5	2.1	205	75
Frequency changer (Heptode)	0	2.0	200	80 (osc. anode 120)
I.F. amplifier (Screened pentode)	- 0.5	2.2	205	75
Second detector (Triode portion of double-diode- triode)	0.8 for min. volume 0.4 for max. volume	4.5	120	—
Output valve (Power pentode)	0	13.0	250	250

Voltage across valve heaters, 4.0 volts A.C.

Voltage across mains rectifier (anode to anode of valve), 320 volts.

Voltage drop across loudspeaker field winding 75 volts.

side of the speaker field winding. Quite likely a high reading will be obtained from one side of the winding but none from the other side. An indication is thus obtained that there is a break in the speaker winding. Too high an anode voltage at any particular valve anode indicates—

1. Voltage dropping resistance in anode circuit is too low in value, or is short circuited. It may be that the anode resistance is defective.

2. Valve emission is falling off. Emission should be tested outside the receiver by applying correct operating voltages to all the electrodes and checking the anode current reading.

3. Grid bias is too high. This may be caused by a defective bias resistance.

If *all* the anode voltage readings are too high, the heater circuit should be examined for a short circuit or a resistance in the leads (such as a poor connection) which would reduce the heating current applied to the valves.

If the anode voltage of any particular valve is below normal the following points may be suspected—

1. Short circuit or partial short circuit on grid bias resistance. In this respect, it should not be overlooked that the metallic screen on a valve is at cathode potential, which, owing to the position of the grid bias resistance, may be at a fairly high *positive* voltage. Any metallic object between the metalized layer on a valve and the bare chassis will therefore short circuit the bias resistance and reduce the anode voltage. A broken down decoupling condenser across the bias resistance may be the cause.

2. Anode circuit resistance too high. This may be brought about by deterioration in a resistor element.

3. With battery valves, the grid bias battery may be defective, resulting in too low a value of bias being applied to the valve.

If the anode voltages of all the valves are below the correct values, reduced voltage from the mains rectifier is indicated. This may be brought about by diminished emission in that valve owing to its useful life becoming finished. An excessively high resistance in the main H.T. + or H.T. - lead from the mains unit to the receiver proper will also reduce the anode voltage applied to each valve.

ALIGNING SUPERHETERODYNE CIRCUITS

Unless the signal frequency, oscillator and intermediate frequency circuits are accurately tuned to their respective frequencies, a superheterodyne receiver cannot work at all satisfactorily. Even a slight misalignment makes itself evident by producing a reduction in sensitivity and selectivity of the receiver.

In general, the alignment or ganging of the circuits is affected by anything that influences their capacity or inductance, and to obtain the best results it is necessary to ensure that, once the alignment has been carried out, nothing should be done to alter these factors. An alteration in the wiring of one of the circuits is enough to throw it out of alignment, and so is the fitting of a different valve. In both of these instances, therefore, the corresponding circuits should be re-trimmed. All that is required in these cases is to turn slightly the trimmer adjusting device of the circuit affected. This should be done during reception of a station, with the volume control set at the minimum consistent with clear reception. A very small movement of the trimmer adjuster is all that is generally needed to bring the circuits into proper adjustment again, this being evidenced by an increase in output, *if the A.V.C. has been disconnected*. The latter precaution is necessary before the adjustment is made, otherwise the output is maintained constant regardless of the misalignment

to a certain extent. There will, however, be an appreciable difference in selectivity as the trimmer is adjusted.

Aligning I.F. Circuits. Before an attempt is made to adjust any of the I.F. transformers of a superheterodyne receiver, it should first be found out what is the frequency to which they require to be tuned. The intermediate frequency varies not only among the different makes and designs of receiver, but also in the various coils constituting an I.F. tuning element. For example, in one commercial type of receiver, which employs one I.F. valve and two I.F. transformers, the respective frequencies to which the I.F. transformer windings are tuned are as follows—

Input transformer: Primary 128 kc/s, secondary 128 kc/s;

Output transformer: Primary 128 kc/s, secondary 125.5 kc/s.

When aligning the I.F. stages of a receiver such as this it will, therefore, be useless trying to make do with one test frequency.

In taking measurements of the output voltage it will be found an advantage to keep the strength of the input test signal low, so as to avoid risk of overloading one of the I.F. valves and also because small differences in the output meter readings are more easily observed, with consequent greater exactitude in the final adjustment. The A.V.C. system will operate to the detriment of the tuning alterations made, since it levels up the output voltage. It should be disconnected, preferably at the source of A.V.C. voltage, whether diode or Westector. The local oscillator should be stopped from generating by short circuiting one of the oscillator coils, such as the grid or anode coils, or the cathode injection coil.

An output meter is connected across the loudspeaker terminals on the receiver, or across the primary winding of the output transformer. An instrument reading up to about 5 volts A.C. will do. A modulated oscillator is then either coupled loosely to the control grid wiring of the last I.F. valve, or connected to its anode and earth. After having set the oscillator to the frequency of the primary winding of the last I.F. transformer and switched on both the oscillator and the receiver, the primary trimmer is turned very slowly to give maximum deflection in the output meter. Then set the oscillator to the frequency of the secondary winding of the transformer being aligned and adjust the corresponding trimmer as before. When this I.F. transformer has been correctly aligned, the procedure outlined above should be repeated with the other transformers, always testing towards the aerial circuit rather than away from it.

Aligning the Oscillator. After the I.F. circuits have been tuned, the modulated oscillator should be connected to the signal input circuit of the frequency changer valve and switched on to about 1500 kc/s. The short circuit placed across the oscillator circuit

during the I.F. circuit alignment should be removed and the receiver tuned to 200 metres (1500 kc/s). The oscillator trimmers should then be adjusted slowly until the maximum reading is obtained in the output meter. It is often more satisfactory to carry out this test with the trimmers on the H.F. side of the receiver screwed fully up (clockwise rotation). After these H.F. circuits have been ganged, the oscillator trimmer should be slightly readjusted to give maximum output meter reading.

Ganging H.F. Circuits. The receiver should be tuned to a low wavelength, say 200 metres (1500 kc/s) as for the oscillator adjustments. An oscillator may be employed, connected to aerial and earth, or a fairly weak radio signal. As with the other circuits, the trimmers should be adjusted, beginning at the one farthest from the aerial circuit and working towards the aerial circuit, to give maximum deflection in the output meter.

TESTING WITHOUT A MODULATED OSCILLATOR

There are frequently occasions when it is desired to examine a superheterodyne receiver with the aid of nothing more than a milliammeter. A large percentage of the faults occurring on the receiver can be traced without the use of a modulated oscillator or output meter, and the following notes are intended to indicate the lines on which such tests can be carried out.

It will be supposed that a receiver has broken down and gives no reception whatever. In order to locate the fault, the following tests may be made in the order given—

1. Apply voltage from gramophone pick-up to second detector circuit. If the production is in order it may be assumed that second detector and L.F. stages are working.

2. Join aerial to plate terminal of H.F. valve via a 0.0001 μ F condenser. This cuts out the H.F. valve. If the fault is in that valve the set should work; but even if the receiver is still defective the aerial may be left there until the test is finished.

3. Test frequency changer by inserting milliammeter in first detector anode circuit and then short circuiting an oscillator coil—cathode injection, grid or anode oscillator coil, depending upon the type of oscillator employed. If the frequency changer (first detector and oscillator) is working properly there will be a deflection in the meter when the coil is short circuited.

4. Take anode current readings of I.F. valves.

These tests will usually reveal the location of a fault. It remains to test the defective valve outside the receiver, and the circuit for continuity or short circuit. In taking anode current readings it is advisable to connect the meter in that part of the circuit farthest removed from the anode terminal, so that the effect of the meter windings and leads in the receiver will be reduced

to a minimum. A condenser of $0.1 \mu\text{F}$ or $0.01 \mu\text{F}$ should be joined across the meter terminals.

The remarks under the respective headings may now be amplified—

1. If no sound is heard when pick-up voltages are applied. Take anode current readings of second detector and output valves. If a current reading is too high, suspect grid bias resistance being short circuited, possibly by broken down by-pass condenser connected across it. Test for continuity as indicated by readings.

2. The receiver under these conditions is very unselective. When the defect has been remedied, therefore, a lot of interference will be experienced until the aerial has been put back on to its correct terminal. If signals are received only when the aerial wire is joined to the H.F. valve's plate terminal, the anode current consumption of this valve should be found out and its circuit examined.

3. The oscillator may be tested by inserting a low-reading milliammeter into its anode circuit and rotating the tuning condenser. A small alteration in reading should be observable as the condenser vanes move round, if the valve is oscillating. Another test, and a more satisfactory one, is to short circuit an oscillator coil while the meter is in circuit, and note if there is a deflection by the needle. As mentioned under the section dealing with optimum heterodyne, the oscillator voltage has to be within certain limits of a given voltage. In the modern heptode frequency changers, if this voltage is not generated the mutual conductance of the valve is reduced. This is a point that should not be overlooked by battery users when the batteries are running down. It is also important in battery receivers to maintain the screen grid voltage if a screen grid valve or pentode is employed as frequency changer. If this is not done, there will be difficulty in maintaining the oscillations, particularly on the longer waveband. The correct screen grid voltage is about $4\frac{1}{2}$ volts higher than that at which oscillations cease when the receiver is tuned to a loud station near the highest wavelength reading on the long waveband. The voltage on the screen grid should be reduced gradually until the signals stop coming through and then increased by $4\frac{1}{2}$ volts.

4. The flow of anode current is not an assurance that the entire stage is working properly, of course. On the other hand, it is assumed that no test oscillator is available, and as the I.F. circuits cannot be tested for alignment without such an instrument, some other device will have to be used. The most satisfactory check on the I.F. transformers, without an oscillator, is to find the resistance of the windings. If the stated resistance of each winding is 150 ohms, for example, yet under test one

winding only shows 100 ohms, then it can be assumed that there is a short circuit in the coil. A higher resistance than the correct one will indicate a poor connection, probably at one of the terminals, or a partial break in the wire. The actual resistance of the respective windings should be found out while the coils are in good working order and noted for reference—it may be any value from 5 to 170 ohms, depending upon the type of receiver the transformer is fitted to. If a new I.F. valve is fitted at any time, the respective condenser trimmers connected with its input transformer secondary and its output transformer primary should be adjusted to give maximum loudness from the loudspeaker while receiving a station with the volume control turned to the minimum value possible.

SOME GENERAL NOTES ON MAINTENANCE

The actual types of valves employed in a superheterodyne receiver have a profound influence on its working. It is of the utmost importance, therefore, that the valves be in their correct places and that when a new valve is fitted, it must be of precisely the same type as the one it is to replace. Even so, a noticeable difference in working may result, especially if the new valve is a frequency changer, owing to the alteration in effective inter-electrode capacities placed across the circuits. The circuits associated with the new valve should be re-trimmed, the movement of the condenser trimmer adjusters being done with extreme care as only a slight alteration is usually necessary.

Background noise is generally increased by the use of a small aerial. In A.V.C. receivers it is particularly noticeable that the smaller the aerial the more noisy is reception. Speaking generally, a high aerial about 60 ft. in length should give the desired results with reasonable freedom from background noise. It should not be overlooked that two I.F. stages will usually produce more noise than one. Other causes of noise are resistances, either defective or run too close to, or in excess of, their rated value; a speech coil out of centre; poor earth connection; intermittent contacts in wiring or a component; broken aerial wire; and faulty switches. The latter is a frequent cause of noise in a superheterodyne, and the switch contacts should be well attended to in respect of cleanliness and firm contacts.

Instability may be caused by a defective H.F. or I.F. valve, and is evidenced by a whistle. It may also be caused by a by-pass condenser in an H.F. or I.F. circuit becoming disconnected.

Microphony may be set up by the vibrations of the loudspeaker diaphragm causing a movement of the tuning condenser vanes if the loudspeaker is mounted in the receiver cabinet. An effective remedy is to insert a rubber pad between the ganged condenser

and the chassis, or between the chassis and the cabinet. Microphony does not always produce the well known low pitched howl. It may sometimes cause distortion only, by accentuating notes in the lower part of the musical scale. The possibility of a defective H.F. or I.F. valve should not be overlooked.

Motorboating may be caused by a defective decoupling resistance in the A.V.C. system. The resistances should be checked

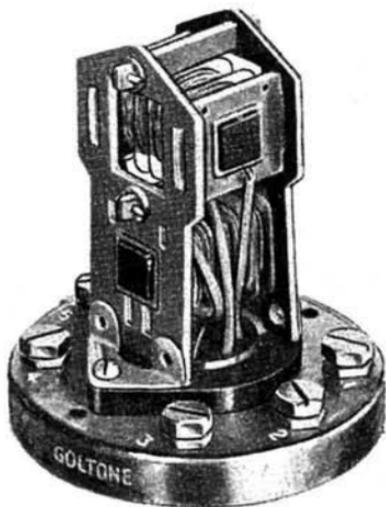


FIG. 83. GOLSTONE WHISTLE SUPPRESSOR

in each circuit and if any doubt exists about any particular resistance it should be replaced by one of about half a megohm. Values up to one megohm are used for this purpose. The A.V.C. decoupling condensers should also be checked for correct working. They may be replaced by non-inductive condensers of $0.1 \mu\text{F}$ capacity.

Whistle Suppressors. Anyone who is troubled by whistle interference that is caused by strong local stations, should consider the advisability of utilizing one of the various types of whistle suppressors that are available. By "whistle interference" is meant that type of whistle whose pitch varies with the setting of the tuning condenser, as distinct from the common heterodyne

whistle that is caused by the combination of two transmitted signals and whose pitch remains constant regardless of the setting of the tuning dial. One type that employs two rejector circuits in series is shown in Fig. 83. In practice, the whistle suppressor is connected into the aerial lead to the receiver and the latter is tuned to the station interfered with most severely. The variable condenser of one of the rejector circuits is then altered in capacity until the interfering whistle is greatly reduced in intensity with respect to the desired signal. Before this point is reached, the signal will become weaker, but this is an advantage because the signal is usually excessively loud and by diminishing its strength less strain is thrown upon the A.V.C. and there is also less risk of overloading the valves.

After one whistle has been tuned out, the receiver is tuned to another station that is interfered with by a whistle. The remaining rejector circuit is now tuned by movement of its variable condenser until the interfering whistle is reduced to a minimum. After this adjustment has been carried out, the receiver is again tuned to the first station and a final tuning of the first rejector circuit is carried out. The two rejectors may now be left and should not require readjustment so long as the stations to which they are tuned transmit on the same wavelength.

TESTS ON AUTOMATIC VOLUME CONTROL

Although it is not very practicable to test an A.V.C. device during its operation when only ordinary fault-finding instruments are at hand, it is often possible to verify whether the control is effective by taking a reading of anode current flow in the circuit of the controlled valve. It should not be assumed that the A.V.C. is working properly unless all the controlled valves give an indication to this effect. If one valve remains unaffected by the A.V.C. then the circuit should be traced back from the grid, decoupling resistance and condenser, to the A.V.C. valve or Westector. Should none of the controlled valves give a response to the A.V.C., it may be assumed that the control element (valve or metal rectifier) is at fault. This should be examined for defect or short-circuit, and also the load resistance should be tested.

The procedure for testing anode current to check the working of the A.V.C. is as follows. Insert a milliammeter in the anode circuit, as far away from the valves as the circuit will allow, shunting the meter with a condenser of 0.1 or 0.01 μ F capacity. Switch on the receiver and tune to a station that is received at loud strength. As the signals are tuned-in the meter needle should dip towards a lower reading and as the station tuning is passed over, the needle should rise to a higher reading again. This is

obviously the result of correct A.V.C. working, for a strong signal will produce a large bias voltage at the A.V.C. rectifier which, on being applied to the controlled valve must diminish the anode current flow. When the station tuning point is passed, the signal applied to the A.V.C. rectifier is diminished and so is the bias voltage produced by it. Consequently, as the controlled valve receives a smaller bias, the anode current increases.

Sometimes it will be found impossible to test in the manner described above, owing to the unstable condition of the receiver brought about by the insertion of the meter in the valve anode circuit. In such cases it is possible to test the working by taking readings of the voltage developed across the corresponding bias resistances. As the anode current flow is dependent upon the efficient working of the A.V.C. system, so must be also the voltage drop along the bias resistance inserted in the cathode lead to maintain a minimum bias on the grid since this voltage depends upon the respective anode current flow. It is a comparatively simple matter to check the voltage across the fixed bias resistance with a reasonably high resistance low reading voltmeter. If the respective valve is metallized, this voltage reading is generally most easily taken by connecting the voltmeter between chassis and metallized layer on the valve.

To carry out the cathode voltage test, proceed as follows: Join the voltmeter across the bias resistance, switch on the receiver and tune to a station that is received loudly. Now pass over the tuning point until the signal is lost and no signal is received. If the A.V.C. system is working properly, there will be a *reduction* in voltage across the bias resistance as the station is tuned in, and an increase in voltage as the tuning point is passed and the no-signal position is approached. This is clearly explained by the series of events during tuning to, and off, a station. At the correct tuning point, incoming signal voltage is highest, A.V.C. voltage applied as bias is maximum, anode current of controlled valve is minimum and thus the voltage dropped along the fixed bias resistance ($R \times i$) is at a minimum. As the tuning point is passed over the reverse events take place, producing an increase in voltage drop along the resistance. A station that is received loudly should be employed during this test so that the greatest difference of potential drop along the bias resistance will be observable. The actual voltage to be expected will vary with the design of receiver, and home constructors should find this out while the receiver is working properly. Generally it is about 1 volt during reception of a loud signal and about $2\frac{1}{2}$ volts at the no-signal position of the tuning dial.

The delay bias resistance should not be overlooked in these

tests. It can be tested by checking the voltage drop across it, usually about 2 volts.

In respect of the various A.V.C. systems at present in current practice in superheterodyne receivers, as outlined earlier in this book, it should be remembered that the easiest method of preparing to locate a fault is to take measurements of voltages and anode current values in the various circuits while the receiver is in good working condition. This will enlighten the reader far more than whole chapters of fault-finding instructions, for the systems of A.V.C. and methods of application are many and very varied.

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