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ERRATA

Page 41:

Column 1, Paragraph 3, Line 9, should read: "inadequate and pointed to the need in the high frequency..."

Page 43:

First complete paragraph, Line 10, should read: "gain variation of only 10% was obtained."

Page 44:

Line 3 should read: "signal to noise ratio was then obtained."

Page 45:

Paragraph 2, Line 5, should read: "pertaining to the problem are pertinent."

Page 46:

Line 4 should read: "detuned from the carrier exciting them. The latter..."

Page 48:

Paragraph 1, Line 3, should read: "assymmetrically located plate will not contribute more..."

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ALL WAVE RECEIVER PROBLEMS

BY

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Delivered before the Radio Club of America
October 10, 1934

CIRCUIT DESIGN PROBLEMS

The important requirement that radio receivers designed for use in the high frequency ranges provide the same effectiveness of performance as has become commonplace in the receivers designed for use in the normal broadcasting range requires something more than the extension into the higher frequency ranges of the conventional circuit design methods which have made the broadcast receiver possible. It has, on the other hand, required a careful re-examination of the principles underlying those methods of design and the working out of new and especial applications of those fundamentals to the specific conditions encountered in the high frequency ranges.

The mere fact that receivers of this type are necessarily of the multirange type introduces the complicated problem of switching of high frequency circuits completely lacking in broadcast receivers: it introduces the extremely serious problem of adapting the highly standardized components of the relatively low frequency broadcast receiver to the high frequency field and introduces the unusually troublesome problem of providing for the use of a single antenna over so wide a frequency range as to make the conventional receiving antenna a negligible portion of a wave-length long at one end of the range and perhaps more than a complete wave length at the other.

Early attempts to provide economically usable multirange receivers in this field completely evaded many of these problems by the omission of all selection and amplification between the antenna and first detector. The extremely unfavorable image response, the relatively low signal to noise ratio and the usually low sensitivity and effective selectivity of such arrangements quickly proved them inadequate and pointed for the need in the high frequency ranges of circuit elements analogous in their performance characteristics to those employed in the broadcast range.

Thus, experience has established the fact that present tubes can be made to function as radio frequency amplifiers with a much more favorable signal-to-tube-hiss ratio than can be attained in first detector or converter circuits and a marked increase in usable receiver sensitivity is therefore obtainable when one or more high gain radio frequency stages are arranged to supply an augmented signal voltage to the converter grid thus "swamping" the noise contributed by the latter tube. Image ratio is improved, as radio frequency tuned circuits are cascaded, proportionally to Q_n where "n" is the number of tuned circuits and "Q" is the figure of merit of each, assuming they are alike. At the same time, where reasonable shielding is employed, one or more radio frequency tuned stages afford acceptable freedom from interference caused by strong signals or electrical noises getting directly into the intermediate frequency amplifier. Radiation is likewise materially reduced since tuned circuits and tubes, preceding the oscillator section of the circuit, act as effective "buffers".

The importance of antenna coupling circuit gain cannot be over emphasized since, in addition to all of the above advantages, this factor determines the ultimate usable sensitivity of the receiver in favorable locations. While tube noise in a radio frequency amplifier stage may be markedly less than that contributed by a converter stage, this noise limits the amount of usable amplification, of any type, which can follow this tube. Antenna circuit gain, then, is of unique importance and every effort to maximize it without complication, is worth while.

INTERSTAGE COUPLING SYSTEMS

Early study of these factors led, immediately, to the measurement of the relative figures of merit, "Q", of some twenty coils, of suitable physical sizes, designed to operate between 8 and 20 mega-

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cycles in conjunction with standard broadcast type tuning condensers.

APPROXIMATE VALUES OF "Q" FOR VARIOUS PRACTICAL COILS AT EIGHT MEGACYCLES

Coil #	"Q"	Dia.	Turns	Wire #	T / inch	Comments
1.	101	1.0	5.0	18	20	
2.	116	1.0	5.5	18	10	
3.	358	1.25	15.0	18	12	Small C to tune
4.	68	1.0	5.5	30	16	
5.	116	1.0	5.5	24	16	
6.	130	1.0	6.0	20	10	
7.	141	1.25	6.0	20	10	
8.	60	1.25	6.0	30	10	
9.	124	1.0	6.0	16	10	
10.	113	1.0	6.0	14	10	
11.	84	1.0	6.0	24	10	
12.	131	1.0	6.0	18	10	Chosen for tests
12.	145	1.0	6.0	18	10	Tested at 9MC.
13.	141	1.25	5.5	18	12	
14.	135	1.25	5.5	18	8	
15.	113	1.25	5.5	18	6	

The table gives the results of some of the more significant of these measurements obtained with each coil placed in a two inch square aluminum can of suitable length.

From these data the best practical coil was selected and tested in a tuned radio frequency stage using various coupling means. As might have been expected, discouragingly low gains resulted from the use of the conventional, tuned, inductively coupled step-up transformer in the plate circuit. This led to the coupling arrangements shown in Fig. 1 whereby a markedly higher tuned impedance was included in the plate circuit of the amplifier tube.

This circuit, including the necessary filtering, while sufficiently stable, varied widely in gain from 6 down to little more than 1. The fact that the gain was maximum when the capacity was nearly minimum substantiated the fact that, as has been generally recognized, the use of broadcast capacity range tuning condensers with the necessarily minute inductances to cover the high frequency ranges, is a serious limitation to the maintenance of the amplification at a high value throughout the frequency range.

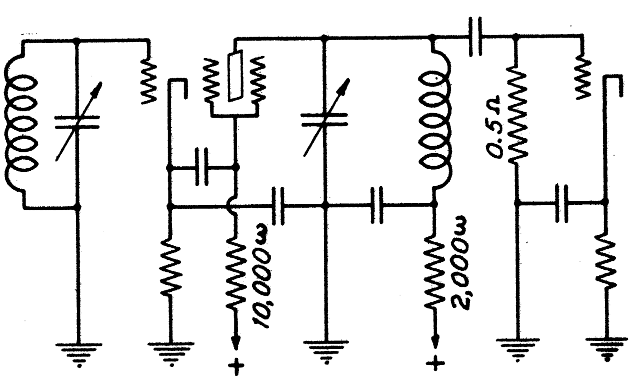


Fig. 1

With these facts in mind, after it had been determined that anything as small as a 100uuf variable condenser would not afford broadcast band coverage, serious consideration was given to the possibility of using larger inductances with the customary broadcast type ganged tuning condenser. A few tests indicated that a marked increase in inductance would be necessary to attain a reasonable gain from amplifier stages operating at these high frequencies. At the same time, the equally great need for improvement in antenna circuit gain was kept in mind.

The use of a small fixed condenser in series with the usual tuning capacitor was considered, but not tried because of the inevitable crowding at the high frequency end of the dial, the increased losses to be expected unless a fixed air condenser were to be used, and the limitation in tuning range. An inductively coupled tuning transformer, as indicated in Fig. 2, was next considered, tried, and found to function fairly satisfactorily, though with little improvement in gain in return for the increased switching complication, bulk and cost.

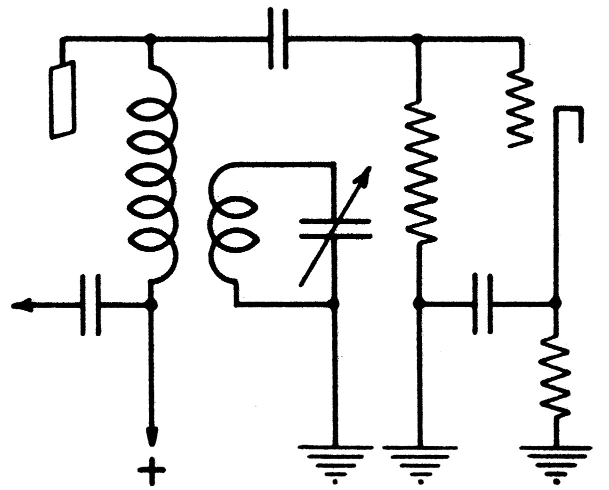


Fig. 2

Theoretical considerations indicate that, in an ideal system, connecting a given condenser, "C", across a few turns, "n", of a given coil having "N" total turns, is equivalent to putting a capacity,

$$C\frac{n^2}{N^2}$$

across the whole coil. Thus, if such a "tuning auto-transformer" consisted of a condenser of 350uu fd capacity connected across half of a coil of 2.5 micro-henries total inductance, as indicated in Fig. 3, this combination would be approximately equiva-

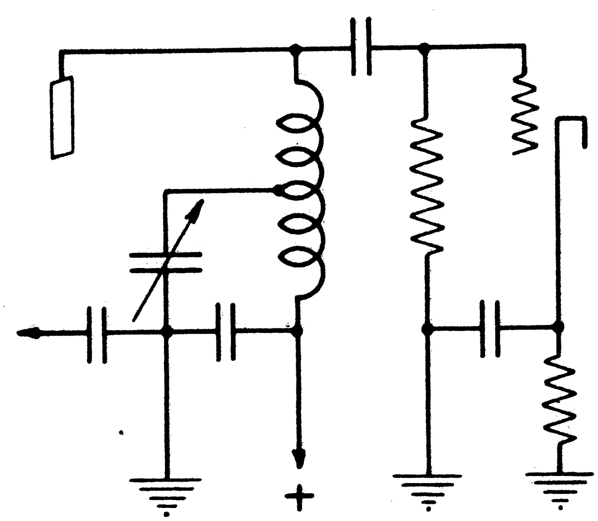


Fig. 3

lent to 350uufd connected across an entire coil of 0.65 micro-henries and would tune to about 10 megacycles in each case. First tests with this type of system used in a tuned radio frequency stage indicated that while the theoretical maximum increase in gain of four to one was not attainable, it can be approached sufficiently close to afford a marked improvement in performance.

Considerable subsequent experience with this system, used as an r-f coupling means covering a frequency range from 8 to 20 MC has shown it to be very effective. Gains as high as 35 were found possible using completely practical circuit elements with a comparative small change of gain with frequency over the band of any one coil. Variations of gain over a single band of less than two to one was easily attainable and in an exceptional case a gain of only 10 per cent was obtained. Frequency ratios of 2.25 to 2.75 are attainable in practical arrangements with tuning curves substantially the same as those resulting from the use of the same elements in conventional type of circuits.

It is to be noted, however, that the capacity resident in the circuit wiring and the dielectric losses in that capacity become of especial importance in this type of circuit and must be kept at the irreducible minimum for best results.

ANTENNA COUPLING SYSTEMS

Returning to consideration of the problem of high antenna gain, using broadcast type tuning condensers, a study was made of the possibility of using the same center-tapped tuning arrangement in order to maximize the resonant rise of the antenna voltage into the grid of the r-f tube and to eliminate tracking difficulties when used in conjunction with this type r-f coupling system. Of the many possible, two (fortunately the simplest) coupling means were found to be the best.

Fig. 4 indicates one simple antenna coupling method, in which the small series antenna condenser may have a capacity between 10 and 15uufds, while the alternative is to connect the antenna to the top of the coil through a capacity of about 3uufds. Subsequent experience has shown that while the results from the two systems are quite similar, practical switching considerations may give one some preference over the other. Using either connection, gains ranging from 3 to 6 have been experienced using a 400 ohm dummy antenna. In general, modification of existing excellent practical receiver circuits to incorporate this principle has resulted in over 50 per cent improvement in antenna circuit gain.

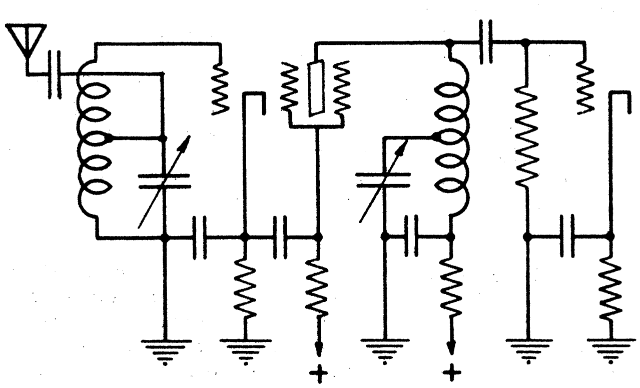


Fig. 4

In the combination of this antenna coupling system with the similar r-f system oscillation occurred on resonance in spite of all the usual filtering precautions which had been incorporated in the set-up.

This instability defied all attempts at its elimination, though thorough shielding, considerable component separation, and separate battery power supplies were tried. A study of the circuit then revealed the possibility that since, at these high frequencies, the coil and condenser leads constitute a considerable part of the total inductance of the tank circuit, the very short, low impedance rotor shaft connecting the usable sections of the ganged condenser might well provide sufficient coupling between the grid and plate circuits, as indicated in Fig. 5. to cause the instability noted. Checking this theory by using separate tuning condensers substantiated this fact.

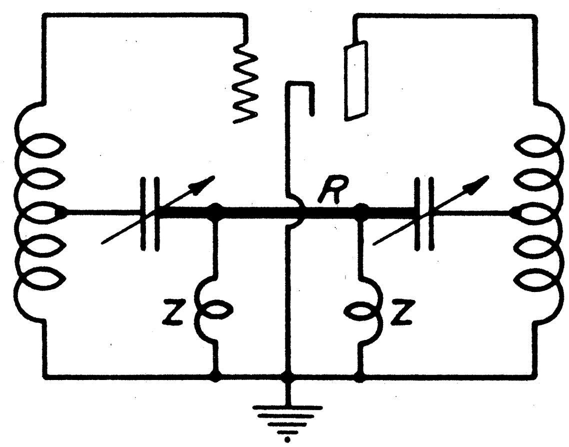


Fig. 5

The elimination of this coupling by the centralization of the several groundings in the circuit at one point in the variable condenser structure as shown in Fig. 6 resulted in complete stability at all frequencies.

In fact, it was rather astonishing to find how little coil shielding and part or circuit separation were needed to provide complete stability in such a high gain system after this cause, which has proba-

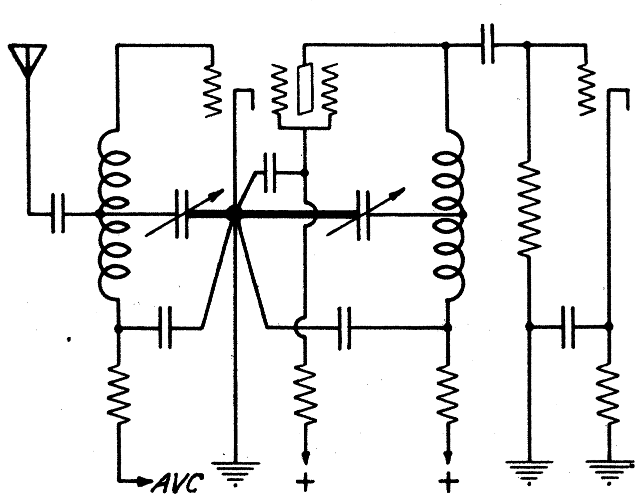


Fig. 6

bly always existed in less aggravated form, was eliminated. Marked improvement in sensitivity and signal to this ratio was then obtained, with complete stability, using the entire system as indicated in Fig. 6.

COIL SWITCHING SYSTEMS

Experience with the practical embodiment of these principles has led to simple efficient coil switching arrangements. Careful measurements have shown a negligible difference in efficiency between parallel and series coil switching systems so that different physical set-ups may give either a 5 per cent advantage over the other. For that reason, both arrangements have been used with success, choice depending on convenience. A simple series coil switching arrangement has been devised, embodying all the desirable features which have been mentioned, as indicated in Fig.7, while Fig.8 indicates an equivalent circuit utilizing the parallel coil arrangement. It will be noted that in either circuit the maximum benefit is derived from the grid and plate "boosting coils" on the highest frequency band and that as more inductance is switched into each circuit for the lower frequency bands, the effect of these coils becomes less and less until, on the broadcast band, their effect is negligible. In this manner it is possible to partially counteract other factors which lessen receiving efficiency on the higher frequencies where it is desirable to concentrate the greatest gain.

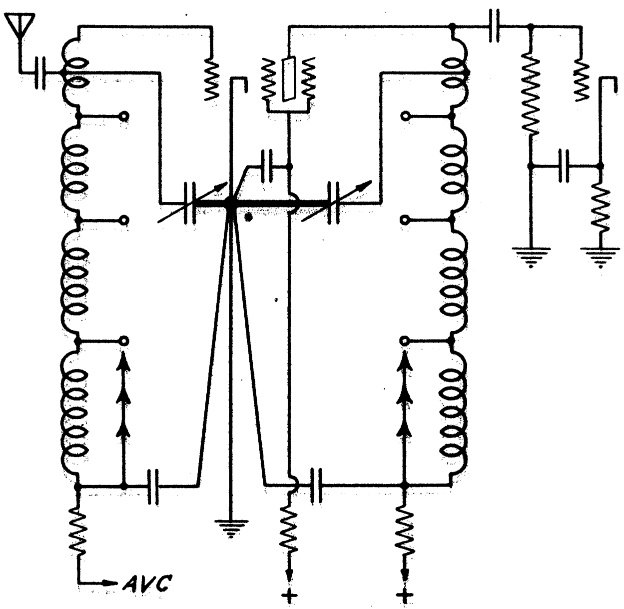


Fig. 7

In order to facilitate tracking and compensate for slight inductance variation in the manufacture of these coil systems, individual trimmers may easily be connected across each of the series coils shown in Fig. 7. Padders may be conveniently added, to either circuit, if desired, by providing an extra set of contacts on the coil switch. However, padders have not been found generally necessary or desirable. Due to the use of a small condenser in series with the antenna lead, wide changes of antenna characteristics have a negligible effect on the tracking of the antenna and r-f circuits.

In general it may be said that the circuit arrangements, the development of which has been here described, provide highly effective means for securing high radio frequency stage gain as well as antenna circuit gain and thus provide performance characteristics for short wave receivers comparable with those commonly accepted in broadcast receiver practise. No especial or "tricky" expedients need be resorted to to attain amplifier stability and the resultant mechanical and electrical structure need include nothing but the simplest of coil and switching gear construction.

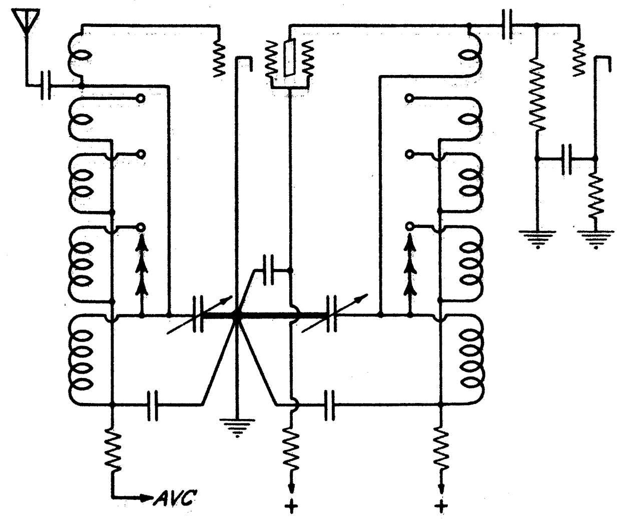


Fig. 8

ACOUSTIC FEED BACK PROBLEMS

The broad subject of regenerative electrical feed back in radio equipment has been of interest and importance ever since the introduction of the vacuum tube amplifier and detector provided such degrees of amplification as made possible sustained oscillation through the ever present feed back couplings inherent in the equipment. The possibilities of the utilization or elimination of this phenomena were early recognized and the means for its control or neutralization thoroughly investigated and established.

On the introduction of the loud speaking type of reproducer into the radio system an extension of the feed back principle including, in addition to the electrical couplings, a mechanical or acoustic coupling resulting from the mounting of the loud speaker in or near the mechanical structure of the amplifier system gave rise to acoustic regeneration resulting in what is termed "acoustic howling" and requiring new analysis of the problem and new methods and expedients for its elimination. While the presence or absence of purely electrical feed back coupling may markedly influence the over-all stability of an amplifying system including an acoustic feed back element, the methods for the analysis and elimination of the purely electrical feed back are so well established and generally understood that no further reference to them need be made in this discussion.

The development in the last few years of extremely high gain receivers in ever decreasing physical size and the therefore unavoidable increase in acoustic couplings between the several parts of the system has made essential the careful analysis of the effect of such couplings on the over-all stability and the devising of means for its reduction or elimination. It is, therefore, the purpose of this portion of the paper to review work done in this field and to suggest methods for the experimental analysis of this phenomena and to suggest such modifications in the electrical and mechanical structure of conventional forms of receiving equipment as will offset the influence of such acoustic couplings as are unavoidable.

AUDIO MICROPHONICS

Of all acoustic feed back trouble audio microphonics are, perhaps, the most widely known and understood. They result when sound energy from the loud speaker causes one or more of the audio tubes or the detector to vibrate. The condition necessary for this feed back to cause howling is fulfilled when the audio amplification between the detector and the loud speaker is equal to or exceeds the acoustic attenuation between the loud speaker and the detector. The tendency toward microphonic howling is therefore, a function of the audio gain, loud speaker efficiency, acoustic attenuation between speaker and detector and any mechanical resonances in the tube or the speaker.

While this variety of howl is no longer of great importance in practise as the result of the general use of relatively low audio gains and ruggedly constructed tubes certain familiar facts pertaintaining fo this problem are pertinent to later discussion and will, therefore, be reviewed at this point. Reference is here made to Fig. 9 which represents graphically an audio system including the loud speaker and acoustic feed back link, and in which it is assumed that the only effective acoustic link extends to the detector.

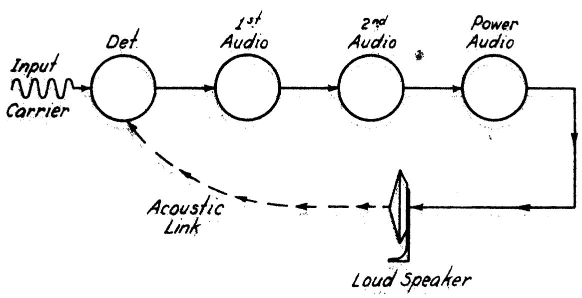


Fig. 9

In the case of the grid leak detector, the microphonic howl occurs when little or no carrier and hence little resulting biasing voltage is impressed on the grid since under those conditions is the tube most effective as an amplifier and highly effective for the modulation of its plate current by the vibration of the grid. In the case of the grid bias type of detector circuit the converse is true since the detector tube acts as an effective audio amplifier only when the applied carrier offsets the effect of the normal grid bias and thus acoustic howling results only in the presence of a relatively strong carrier.

The early investigations into this phenomena suggested simple means of analysis which are still of great utility. Briefly, after disconnecting the loud speaker from the receiver circuits, maintaining its physical connection with the amplifier, however, the speaker is excited by a conventional audio oscillator of variable and known frequency and voltage and the output signal at the receiver terminals across a load equal to the speaker impedance resulting from this mechanical excitation carefully measured over a wide range of frequency. Hence, and from the above criterion that, to avoid acoustic howls, the acoustic attenuation must exceed the audio amplification it follows that at those frequencies at which the receiver output voltage exceeds the speaker exciting voltage, the system may howl, depending upon the phase relations between the voltages involved. And the amount by which these voltages differ is a direct measure of the tendency to howl or the margin of stability against howling.

For the elimination of howling the phase of the speaker connections should be so chosen to suppress the howl corresponding to the greatest of the several possible tendencies to howl as indicated by the above mentioned voltage differences and the remaining tendencies toward howl provided against by the usual expedients of flexible detector sockets, weighting the detector tube to lower its natural period, damping the detector tube vibration with rubber or felt pads, and reducing the acoustic coupling through the further removal or acoustic insulation of the loud speaker.

It should be noted at this point that the type of howl here discussed is not to be confused with the "motor-boating" sometimes quite similar in sound which, however, results from poor regulation of the power supply unit and overloading of the tubes, commonly the power tube. In practise it will be found that this type of howl may be differentiated from the normal acoustic howl by the measurement of the tendency to howl as outlined above or, as an alternative, the replacement of the loud speaker by headphones, properly loading the output tube, of course, and observing whether or not the howl persists with the negligible acoustic coupling provided by headphones.

It should be further noted that in every case where excitation of the receiver by a carrier is resorted to, the carrier must be completely free of modulation since the presence of modulation probably through something of the nature of super-regenerative action, markedly reduces the tendency toward howling.

HIGH FREQUENCY MICROPHONICS

Like the audio frequency microphonics discussed in the previous section, radio frequency microphonics are not unique in the modern high gain receiver but their troublesome influence has become more evident with the introduction of the superheterodyne and its higher sensitivity and selectivity. Like the audio frequency microphonics they require that a carrier be present since, without it the mechanical and relatively low frequency vibration of tubes and circuit elements can provide no excitation of such a frequency as will be passed along by the R.F. and I.F. stages to the second detector tube. The consequent possible confusion between A.F. and H.F. microphonics can, therefore, be avoided only by preliminary search for the seat of the feed back in the A.F. system by its isolation from the H.F. system and only after any A.F. microphonics have been eliminated can the further investigation into the H.F. stages of the system be effectively carried on.

In general, there are two distinct types of microphonics in the high frequency stages: those arising from the vibration of circuit elements such as variable condensers, padders, coils and connecting leads, etc.; and those arising from the vibration of the tube elements. The former of these, for reasons that will be obvious from their further discussion in a later section can give rise to microphonics only when the system including them is detuned from the carrier exciting them. The former for reasons perhaps obvious from the discussion of A.F. microphonics, can give rise to microphonics only when the system is tuned to the frequency of the carrier and, indeed, are most troublesome when the receiver is precisely tuned to the carrier. Thus, there is provided a simple and easily effected means for localizing the seat of the H.F. microphonics as between the tubes and the circuit elements of the receiver, and the further analysis may then follow.

"ON RESONANCE" HOWLS

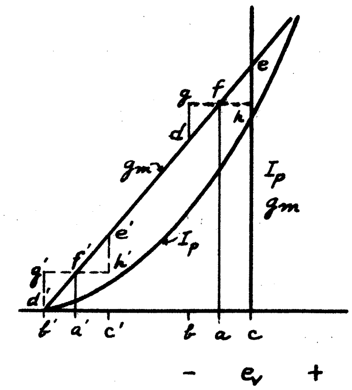
For the further consideration of H.F. microphonics arising in the tube elements more detailed consideration must be given to the phenomena resulting from the vibration of the tube elements when the tube is acting as an amplifier of high frequency voltages. For this reason it is to be noted that the amplifying properties of any tube reside in the fact that as the voltage on the grid is varied the field about it and within the tube structure varies so as to repress or encourage the flow of electrons from the cathode to the plate. If, however, the potential on the grid is maintained at a fixed value and its position relative to the cathode and plate is varied, a similar change in the field about it occurs and gives rise to a change in the amplifying properties of the tube, much as if a change of voltage on the grid had taken place. Obviously then, when the grid is caused to vibrate freely, a cyclic change in the amplification results and any carrier present on the grid of the tube appears in the plate circuit modulated at the frequency of the grid vibration.

It is this mechanically modulated carrier,when applied to the second detector that provides the audio current which makes the acoustic howl possible. And since it is the absolute amplitude of the modulation of the carrier and not merely the ratio of this amplitude to the mean carrier amplitude, i.e., the percentage modulation, that determines the audio output of the second detector, it is usually necessary that the system be precisely tuned to the carrier so that a definite threshold level of carrier at the second detector be exceeded if the acoustic coupling is to be effective in creating howling. The inclusion of the AVC in the receiver in no way modifies this requirement since first, any practical A.V.C. system is by no means completely effective in maintaining the second detector input independent of the applied carrier amplitude and secondly, the very employment of AVC circuits further augments the tendency toward howling at high carrier levels.

This will be more easily evident from Fig.10 if it is borne in mind that the mechanical vibration of the grid through a definite amplitude performs the same electrical function as the application to the grid of a definite A.C. voltage of the frequency of the vibration. In Fig. 10 is shown the characteristic curve of a conventional tube in which the plate current is proportional to the square of the grid voltage.

The amplification possible with such a tube when used in conventional circuits is proportional to rate of change of plate current with grid voltage change, i.e., the mutual conductance, G_m of the tube, which in the square law tube is directly proportional to the grid voltage as shown in the mutual-conductance curve of Fig. 10.

Fig. 10



$$I_p = Ke_v^2$$

$$\frac{dI_p}{de_v} = 2Ke_v$$

It will be evident that if the grid voltage at a definite carrier level adjusts itself to the value a and the vibration of the grid results in an equivalent grid voltage change of bc, there results an amplitude of modulation he and a percentage modulation of he divided by fa which in this case is of the order of sixteen per cent.

Where, however, a high carrier level operating through the AVC mechanism drives the grid bias to the point a' and the vibrating grid provides the same equivalent grid voltage swing as before and as indicated at b'c' there results the same amplitude of modulation as before, as indicated at e'h' but, however, with a greatly increased percentage of modulation as given as the quotient of e'h' divided by f'a' in this case about 100%. And since the AVC functions as to maintain the voltage on the second detector grid approximately of the same value and largely independent of the carrier input, the audio output of the second detector and hence the tendency to howl is much increased by the action of the AVC.

This condition does not, however, obtain where the exponential type of amplifier tube is used since it is the primary characteristic of this tube that the amplification made available through its use varies exponentially with the control grid bias and thus provides a substantially constant percentage of modulation for a given equivalent grid voltage change generated by the vibration of the grid. This will be more clearly evident from Fig. 11, which shows the characteristics of the exponential type tube, and in which the notation is substantially the same as in the previous figure. And while the commonly available remote cut off tubes are probably not strictly exponential in their characteristics, but are, for the most part, largely constituted of tube elements giving two separate square law characteristics, the lower effective amplification constant of this type of tube at highly negative grid biases provides definite usefulness in offsetting the tendency toward microphonic howls through their employment.

It is to be noted in connection with all work in the tracking down of "on resonance" howls and their relation to tube characteristics, that the investigator must assure himself that all variable tuning elements are in thorough alignment, lest the

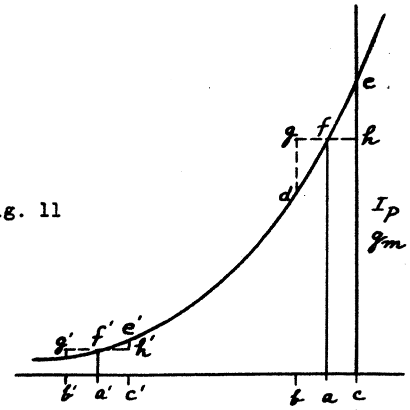


Fig. 11

$$I_p = Ke^{ae_v}$$

$$g_m = \frac{dI_p}{de_v} = Kae^{ae_v}$$

lack of that alignment hide the presence of howling tendencies otherwise discoverable or, on the other hand, the misalignment make possible howls due to causes other than mechanical feed back to the tubes.

For the treatment of "on resonance" howls, substantially the same remedial measures recommended for audio howls are of usefulness with the addition that the employment of exponential or remote cut-off tubes in the offending stages is especially helpful.

"OFF RESONANCE" HOWLS

Where the offending element in the receiver giving rise to acoustic coupling with the loud speaker is one of the tuning elements, a distinctly different type of phenomena from that observed in the case of the speaker-to-tube coupling results. This will be evident from consideration of what occurs when, for instance, the plates of the variable condenser are caused to vibrate through their mechanical coupling to the loud speaker. If they are well centered with respect to one another and vibrate at the frequency of the emission from the loud speaker and are, at the same time so adjusted as to precisely tune the system to the frequency of the carrier being received, their tendency to modulate the carrier will be very little because of the "flatness" of the resonance curve of the circuit of which they are a part. But even though the resonance curve were extremely sharply peaked, such modulation as occurs would not be of the same frequency as that of their mechanical vibration since they would, in fact, throughout a single cycle of movement of the plates, either side of their centre and normal position, detune the system not once, but twice and thus modulate the carrier, at twice the mechanical exciting frequency, if at all. Thus no acoustic feed back can result under these conditions.

If, however, the tuning system is deliberately detuned and sufficiently high carrier levels are applied to the input, a distinctly different condition results. In this case it is evident that as, for instance, the condenser plates are vibrated and the frequency to which they tune the system varies between the upper and lower limits either side of the normal resonant period, only once per cycles of the mechanical vibration does the tuned system approach resonance with the applied carrier and thus the carrier is modulated at the frequency of the mechanical vibration and howling can occur. There is, fortunately, a definite phase relation between the mechanical excitation applied to the tuning system and the resultant modulation which immediately suggests the possibility of the repression of this type of acoustic howl through the reversal of the loud speaker connections. And, indeed, such a reversal does accomplish the expected repression only, however, to bring it into being again when the tuning system is so adjusted as to set it off of resonance on the other side of the carrier and thus really provides nothing but an effective method of recognizing the seat of the coupling. Since, for a given condition of speaker connection this type of howl occurs at only one side of resonance it has been termed, not only "off resonance" howl but "assymetric" and "adjacent channel" howl as well.

It is to be noted that howls from such causes as are here discussed cannot occur on both sides of resonance and that evidence apparently to the contrary indicating symmetrical off-resonance howls is merely indicative of the fact that at least two separate couplings are present and giving rise to the howls and that the search for their location must include more than one of the circuit tuning elements.

The influence of the value of the "Q" on this type of howl should be especially noted as suggested by Fig. 12 in which the resonance curves of circuits having Qs of the ratio of two to one are shown. Thus for a vibrational change of the resonant frequency of the circuit of a value ef or its equal, bc, will result in the case of the relatively low Q and non-selective circuit shown at S in a modulation of the carrier proportional to km while in the case of the more selective circuit shown at T it will result in a modulation indicated by gh with the consequently greater tendency to howling.

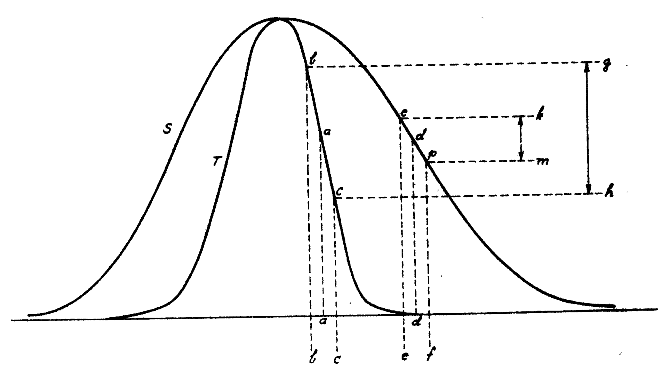


Fig. 12

It will be noted also that the amount by which the tuning system must be off resonance to offer the maximum slope of the resonance curve and hence maximum tendency to howl is also a function of the value of Q, being greater the smaller the value of Q.

It is obvious then that those factors which make for greater selectivity and image suppression as well as all of those performance requirements tending to increase the Q of the radio circuits unavoidably increase the tendency toward off-resonance howls.

Since practical experience shows that the most fertile source of mechanical modulation in the tuning systems resides in the variable condensers, it is of value to give further detailed consideration to this one of the circuit elements. It is generally appreciated that where a metal plate constituted a capacity with two other parallel adjacent and symmetrically placed plates, minor motions of the central plate in a direction normal to the surface of the plates gives little change of capacity, since the increase of capacity brought about by the approach of the moving plate to one of the stationary plates is largely offset by the reduction of the capacity with respect to the other of the stationary plates. And, so in the case of a variable condenser made up of a series of carefully aligned plates, little difficulty resulting from carrier modulation by the axial motion of the plates relative to one another need be anticipated except, perhaps, in the case of the end plate for there must, in any conventional structure, be plates at the end of the structure that are not symmetrically located with respect to two others. To meet this latter condition, special proportions in the end plate spacing as referred to below may be employed but, insofar as mechanical modulation due to uncentralized intermediate plates is concerned, there is only one rational solution and that lies in careful alignment since the art of condenser production has so far advanced that there is left no excuse whatsoever for this type of irregularity.

As for the influence of the end plates there is, of course, no condition under which such an assymetrically located plate will contribute more to the howling tendency than any of the intermediate plates. Careful theoretical investigation indicates, however, that if the end plate is removed from its neighboring plate by a distance approximately forty per cent greater than the normal plate spacing the tendency to howl is minimized.

Aside from these detailed specific points there are several generalizations worthy of formulation and note. Amongst these is the fact that in general, the more compact the variable condenser, the greater is the tendency toward the generation of howl. There is in general no single setting of the variable condenser that will always accompany the greatest tendency to howl; if the tendency to howl is completely resident in the variable condenser that position which provides the highest selectivity will most easily provide a howl: if, on the other hand, some element providing a large portion of the residual capacity, such as padders, etc., is the vibrating member, the greatest tendency to howl will occur with the condenser plates unmeshed: while if the vibrating member is a portion of the inductive element the howl will occur most readily at that setting of the condenser which provides the highest selectivity and since this latter condition is usually realized at the low frequency end of the range it may be said that, in general rotor plate and inductive microphonics occur at the low frequency end while microphonics due to trimmers, padders, connecting leads, etc., occur at the high frequency end of the range; and that a complete check for microphonics can be made only by a careful investigation throughout the range.

There is another interesting point to be noted in this connection and that is summarized by pointing out that, unlike the case of A.F. howling, any stage of the high frequency system is equally susceptible to howl excitation since the phenomena is one of modulation of the already present and successively amplified carrier.

Further, there are several interesting points with respect to the choice of plate thickness that merit consideration.

In general, condenser plates should be thick rather than thin. The stiffness increases approximately as the cube of the thickness and the mass only as the first power. This raises the natural period of the plate and with given energy, the amplitude of vibration decreases directly with frequency. Since the amplitude of condenser vibration controls the per cent of microphonic modulation, the tendency toward acoustic howl decreases as the natural mechanical resonance is increased. Condensers with plates whose mechanical resonance is above 1200 cycles have seldom been found to give rise to acoustic howl.

Such specific expedients for the elimination of microphonics originating in the variable condenser as have, in practise been found useful are the mechanical insulation of the condenser through rubber or felt mountings: the acoustical isolation of the condenser from the speaker through its further removal from the speaker and the elimination of such coupling elements as large dials, knobs, etc.; increased spacing of condenser plates, particularly the end plates; the use of soft metals such as aluminum for the condenser plates and the damping of especially troublesome individual stator or rotor plates with rubber or felt where necessary: the weighting of the entire condenser assembly where evidence of its vibration as a whole is shown as the cause of the howl.

INTERMEDIATE FREQUENCY MICROPHONICS

While the fundamental causes of microphonic howls originating in the I.F. system of the receiver are identical with those inherent in the R.F. system as discussed above, the somewhat different mechanical and electrical properties of the I.F. system provide certain important differences in the tendency to howling. Primarily this is due to the fact that the Q of the I.F. tuned systems is, in general, likely to be markedly higher than that of the R.F. tuned systems and hence greater care to guard against acoustic couplings is necessary. Furthermore the higher value of Q results in a smaller difference between the point of howl and the resonant frequency and thus provides a clue for differentiating between off-resonance howls originating in the R.F. and the I.F. systems. And since, in general the capacity load on the I.F. transformers is less than that in the R.F. stages, the effect of the vibration of connecting wires, etc., is more important and justifies closer scrutiny of these elements in running down the source of acoustic coupling. Loose compression type condensers of the type commonly used in the I.F. stages are a frequent source of acoustic coupling since this type is often set in a wide-open position: and where air condensers are used for this purpose they are more likely to lack the nice plate alignment commonly found in the variable air condenser.

But aside from these specific mechanical conditions, for the elimination of which the same expedients as were recommended in the previous section will serve, there is nothing essentially different to be looked for in the I.F. stages.

OSCILLATOR MICROPHONICS

Insofar as the oscillator circuits are concerned, the modulating influence of the vibration of the oscillator tube will be found to be identical with that of the vibration of any other of the high frequency tubes in the system and will manifest itself by the usual on-resonance howl, and in this the oscillator tube is no more susceptible than any other tube in the receiver. However, this effect is negligible as compared with that resulting from the frequency shift due to the vibration of the oscillator tube which gives rise to assymmetric microphonics.

Assymmetric howls caused by oscillator vibration possess all the characteristics of i-f microphonics except that they occur on weaker signals, or reduced amplification, and becomes more prominent as the oscillator frequency is increased. Thus oscillator microphonics are factors of major importance at short waves.

The greater tendency toward howling due to oscillator vibration will be obvious from consideration of two pertinent factors. First, since the signal delivered to the I.F. amplifier is of a frequency which is the difference between the oscillator frequency and the signal carrier frequency, the percentage change of this beat frequency will be greater than the percentage change in the frequency of the oscillator itself due to vibration by the ratio between the oscillator and I.F. frequencies. And secondly, since the selectivity of the entire I.F. system is operative against the vibrationally varied beat frequency, the I.F. system acts much as if the beat frequency were maintained constant and the resonant frequency of each of the tuned circuits constituting the I.F. system simultaneously and widely varied. Such a combination of conditions obviously provides most effectively for the modulation of any carrier applied to the system by any mechanical vibration which is allowed to effect the oscillator tube or any portion of the oscillator system. Especially severe is this condition in the high frequency ranges where the ratio of the oscillator frequency to the I.F. may be of the order of forty to one and the tendency toward microphonics proportionately great.

Against these unusually severe conditions little more by way of recommendations for their elimination can be made than were made in the preceeding sections. It is usually well worthwhile, however, to provide for the mounting of the oscillator coil not less than one quarter inch from any metal and, where space is available, at even a greater distance. The oscillator section of the variable condenser should be at one end rather than at an intermediate point in the assembly. And, no attempt should be made to align the capacity of the oscillator section with the capacities of the R.F. sections by bending any of the oscillator section plates, especially does this apply to the end plate. If equalization must be accomplished by this crude means, the necessary adjustments should be made on the other sections of the condenser using the oscillator section as the standard.

The author is pleased to acknowledge that the major portion of the section of this paper devoted to the subject of microphonics is the result of an intensive study of the subject made by Mr. David Grimes who is to be commended for his orderly analysis of the several phases of the problem and the compilation of the mass of useful data gathered in his investigation of it.

NOVEMBER MEETING

The November meeting held on November 15th, was devoted to a joint paper by Mr. A.B. Chamberlain and Mr. W.B. Lodge of the Columbia Broadcasting System, on "Broadcast Antenna Systems." In this paper was disclosed a host of data gathered in the investigation of the operating properties of a wide range of antennas as now used in the Columbia System. In these is included various types of vertical and flat-top wire antennas, mast antennas, and combinations of antennas for securing unusual and especially desirable field patterns. This paper will be published in the November issue of the PROCEEDINGS.

DECEMBER MEETING

Mr. Joseph Chambers of WLW will describe some of the especial features of the antenna systems and transmission lines of the 500-kilowatt installation in Cincinnati. In view of the especial characteristics made necessary by the high power employed at WLW, it is anticipated that this paper will be especially interesting.

ROCHESTER JOINT MEETING

The Radio Club of America held a joint meeting with the Institute of Radio Engineers on the evening of November 12, 1934, at Rochester, New York, in connection with the now traditional Fall Meeting of the Institute. Vice President R.H. Langley presided, and called attention to the fact that the Club is three years older than the institute and that this year marks its twenty-fifth anniversary.

The paper of the evening, by I. Wolff, E.G. Linder and R.A. Braden, all of R.C.A. Victor Company, was presented in a most interesting way by Dr. Wolff. It dealt with the transmission and reception of centimeter waves and included a most informing and convincing demonstration. The structure of the special oscillator tube, designed for a wavelength of 9 centimeters, and including a circuit resonant at that wavelength as part of the structure of the tube, was explained in detail with the aid of slides that showed the construction. The tube is based on the basic fact, which seems to underlie chemistry and magnetism as well as electrical science, that an electron in motion is deflected by a magnetic field.

Although this same tube can be arranged for use as a detector of the centimeter waves, the receiver used in the demonstration employed a crystal detector with an audio amplifier and loud speaker. The transmitting tube with its radiating circuit is mounted in a 6 foot parabolic reflector, and a similar pick-up reflector has the receiving resonant circuit and crystal detector. Modulation from a phonograph pickup was obtained first by changing the plate voltage in the transmitting tube, and later by an artificial Heavyside Layer consisting of large argon and mercury tubes whose ionization was varied in accordance with the music. The unmodulated beam from the transmitter was modulated by being sent through this region of ionized gas, and also by refraction and reflection from the gas. The beam was also reflected from small metallic sheets and from the rear wall of the lecture room. Fading effects were accurately reproduced by moving a reflecting surface or the artificial Heavyside Layer. It was obvious from the applause that the paper had been thoroughly enjoyed by Club and Institute members alike.