# PROCEEDINGS

*of the*

# RADIO CLUB *of* AMERICA

Vol. 2 No. 4 June, 1922

# R.C.A. SPECIAL NOTICES

*To the Membership*:

At the last meeting of the Board of Directors the election of three remaining directors to serve for one year permit us to now set forth the complete list of officers and directors for 1922:—

| OFFICERS | DIRECTORS |
|---|---|
| *Pres.*:—G. E. Burghard | E. H. Armstrong<br>P. F. Godley |
| *Vice Pres.*:—E. V. Amy | L. G. Pacent<br>J. F. Grinan |
| *Treas.*:—J. diBlasi | M. Cronkhite<br>W. S. Lemmon |
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| *Rec. Sec.*:—L. C. Horle | N. Dunham |

An interesting series of papers dealing with Broadcast Reception problems are scheduled. Every member will want to keep abreast of the times by participating in these discussions. Come yourself and bring a friend.

Did you know that seven stations constructed by Radio Club of America members were heard across the Atlantic during the recent A.R.R.L. tests?

*Office of Editor of Proceedings*—319 West 94th St., New York.

Walter S. Lemmon—*Editor*
Ernest V. Amy
P. Boucheron
L. Spangenberg.

# Modulation in Radio Telephony

A Paper Presented by L. C. F. Horle* at a meeting of the Radio Club of America, Columbia University.

IN discussing the subject of modulation as applied to radio telephony, I have nothing new to bring to you. In this article, however, I want to review the various methods of modulation which have been used in the past, and also to point out several lines of experimentation which should be followed up.

The problem of modulation is as old as radio. This may not be in the aspect in which we have become accustomed to think about it, perhaps, but, if we define modulation by "the degree to which the wave form of the radio-frequency current departs from constant amplitude", we find that this departure or degree of modulation is involved in the problem which we have been trying to solve in all types of transmitters.

In spark sets the attempt has always been to make the wave-form as nearly sinusoidal as possible. There are two reasons for this. First, the greater the departure from the continuous or sinusoidal wave, the greater has been the resultant interference; and second, the greater this departure the less power we are able to use with a given aerial. Figs. 1, 2, and 3 show more clearly what is meant by this. The last of these figures shows what we have been accustomed to call a highly damped oscillation, since the oscillations die out very rapidly. Fig. 2 shows an oscillation which is not so highly damped. Now, since the *average* height of this wave-form is a direct measure of the power in the circuit, it is evident that the wave form of Fig. 2 represents more power than does that of Fig 3. The height of the first alternation is limited in both cases by the antenna circuit, since the value of the current cannot exceed a certain specified value without causing the antenna insulators to break down, or at least giving rise to serious corona with resultant losses. Hence it is important that the wave decay very slowly in order that the *average* value of the current may be as high as possible, resulting in a maximum of power in the antenna. We have termed this rate of decay the decrement or *logarithmic decrement* of the circuit and have worked to keep it as low as possible.

In the undamped transmitter we have secured a wave-form in which the decrement is practically zero; that is, the wave shows almost no decay and is almost completely sinusoidal. (Fig. 1.) Having secured this long aimed-at result, however, we find that we have a type of radio wave which makes no impression on the usual radio receiver; that is, one which merely rectifies the incoming wave and passes the rectified current through the telephones.

It is of interest to trace through the receiving circuit to see what happens to a wave of this type. Fig. 4 gives the connection diagram of a simple rectifying circuit using a crystal detector. The wave form of the current impressed on the antenna is identical with that shown in Fig. 1, and the voltage which this develops across the detector is also of substantially the same form. But, due to the rectifying

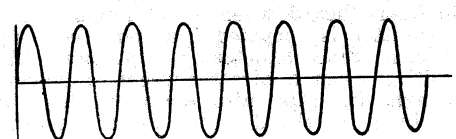

FIG. 1

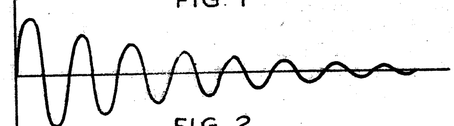

FIG. 2

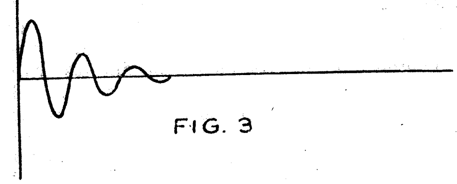

FIG. 3

properties of the crystal, it is converted into a wave form such as is shown in Fig. 5(a). This differs from Fig. 1 only in that the lower half of the wave has been eliminated, leaving merely the half on the upper side of the axis.

It is evident that a wave form approximating this one could be secured if a sinusoidal wave, as Fig 5(c), were superimposed on a direct current, Fig 5(b). In the receiver, however, in order to make the incoming energy effective in the telephones, we separate the rectified current

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into these two components. The telephone and the telephone condenser are a very satisfactory combination for doing this. The telephone condenser will not allow the direct current component to pass, while the telephones, due to their high impedance to radio-frequencies, will not allow the high frequency component to flow. The result is, that the radio-frequency component is forced to go through the condenser, while the D.C. component is forced to flow through the telephones.

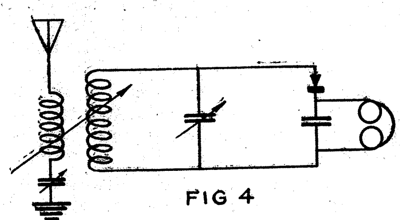


FIG 4

It is evident then that no signal will be audible in the phones if the transmitter is keyed in the usual manner. The only result will be a starting and stopping of a direct current through this part of the circuit. This accounts for the dull clicks which are heard when a continuous wave transmitter is operated near our receiving stations. Since a detector is probably less sensitive when a direct current is flowing through it, this also accounts for the "blocking" of the detector when a nearby and powerful transmitter of the undamped type is in operation, even though the signals from the latter station are not evident in the telephones.

Let us observe what happens when the transmitted wave is modulated, as in Fig. 6(a) where the current in the transmitting antenna never becomes zero, or rather where the wave never dies out. This is rectified by the detector in the receiving circuit as shown in Fig. 6(b), and then is broken up into its two components, Figs. 6(c) and 6(d), as described before. The high-frequency component passes through the telephone condenser, while the low-frequency component goes through the telephones and gives the signal. It is to be noted, however, that it is only the "humps" in the latter current which affect the telephones, and that the D.C. component passes directly through and causes no response. Thus if the modulation is not complete, part of the energy, while it is present in the receiving circuit and actually in the phones, does not make itself at all evident to the operator. It is essential, therefore, that all power that is available in the transmitting antenna be modulated by the voice, if the greatest signal strength in the receiver or the greatest range is to be attained.

This lack of complete modulation is the limitation which kept radio telephony from reaching its present stage of development for many years. The only requirement which had to be met in the construction of a radio telephone system, other than a satisfactory modulation scheme, was a high frequency generator of reasonable capacity. The latter has been available for years in the form of the arc, and recently in the form of the high frequency alternator.

The problem of modulating the arc has been unsolved for years, and even today no satisfactory method is available. This results from the condition which always exists in modulating a generator which of itself has no amplifying characteristics. To accomplish modulation in such a case, it is axiomatic that the power capacity of the modulator must be approximately equal to the power capacity of the generator. Thus in the case of a 5 K.W. arc, we must have as a modulator a source of voice power which is capable of delivering about 5 K.W. At this time there is no such source of power available.

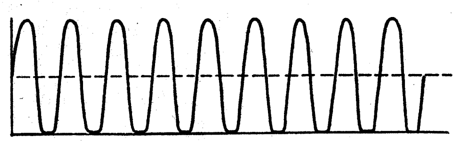


FIG. 5 (a)

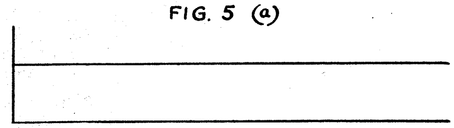


FIG. 5 (b)

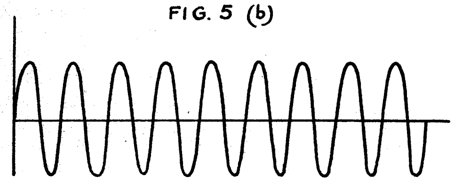


FIG. 5 (c)

This is evident from the inspection of a hypothetical modulation system shown in Fig. 7. Here we have a high frequency generator in shunt with a resistance, the value of which is caused to be varied by means of the voice. Let us observe what the conditions must be if this modulator is to completely modulate the output of the generator. The curves show the wave-form resulting from the operation of the modulator. Where the modulated wave form departs from the undamped, the power is evidently being absorbed in the modulator. The modulated and unmodulated wave forms are shown superimposed and the area of the unmodulated wave form not covered by the modulated wave form is proportional to the power being absorbed by the modulator. It is evident that about as much power is being absorbed in the modulator as is being absorbed in the antenna. This relation is not at all precise, of course, but in a general way, the capacity for power absorption of the modulator must be about equal to the power capacity of the generator.

This unfortunate characteristic is the limitation which applies to all absorption schemes of modulation, and indicates the seriousness of the problem which is met in the attempt to modulate high-power generators such as the arc or high-frequency alternator when absorption methods are resorted to.

Systems have been worked out for the modulation of such generators by various schemes involving the use of the microphone. The oldest type of these is that which uses a telephone transmitter in the antenna circuit, where the change in the resistance of the microphone caused by the voice causes a change in the antenna current much as is shown in Fig. 7. This scheme was worked with varying degrees of success by the Federal Telegraph Co. on the west coast some ten or twelve years ago, and also by the DeForest Co. and the Collins Co. in the east, at about the same time. In all cases the power capacity of the microphone was the limiting factor in the operation of the systems, and invariably because of the limited modulation possibilities of this piece of apparatus, the transmission was extremely unsatisfactory. The capacity of the microphones was increased by water-jacketing and similar subterfuges, but even then only a small fraction of the power was modulated. A transmitter of 10 K.W. was barely sufficient for transmission over ranges of one hundred and two hundred miles, and even this was possible only under very good conditions. These several limitations which militate against the general use of absorption systems for modulation suggest the advisability of two other methods.

The first that suggests itself is one in which the power of the generator is made to vary by a control of its source of power in some manner whereby the criterion of equality of power capacities may be expected not to hold. The second is one in which the *reactance* of some part of the circuit is changed with a resultant change in the wave-length of the transmitted wave, or with a change in the current in the antenna. This latter scheme offers infinite opportunity for experimentation. Several methods have already been devised to accomplish this result, and others may be looked forward to in the future for the complete solution of the problem.

Dr. Alexanderson's method of controlling the high frequency alternator and Mr. Ernest Amy's magnetic modulator are the two that come to mind at this time. In the former the generator is connected to the antenna in such a way as to include an iron core inductance, the reactance of which can be changed by the voice currents. The value of the inductance can of course be changed by providing the iron core with two windings, one of which carries the voice currents, and the other of which carries the working current, the voice current circuit being protected against the induced radio frequency current. The inductance and consequently the reactance of such a coil will depend on the values of the exciting currents in the windings. Variations of the values of these will change the flux

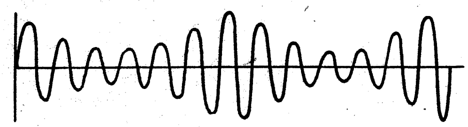


FIG. 6 (a)

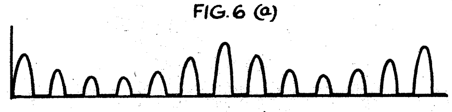


FIG. 6 (b)

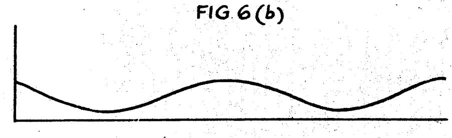


FIG. 6 (c)

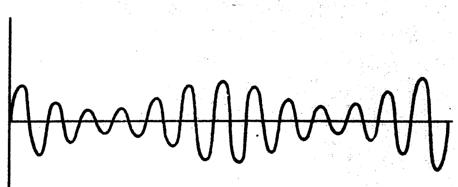


FIG. 6 (d)

density in the core, and hence the inductance of the coil as a whole. If such a coil is placed in the antenna circuit, or in a local circuit coupled to the antenna circuit, and tuned to resonance with it, the wave length of such a circuit will be varied by the voice current flowing in the exciting winding, and this change in wave length will cause the current in the antenna circuit to be modulated by the voice. This method has the advantage that relatively small amounts of power will cause rather large variations in the reactance of the coil, and hence vary the current in the antenna between very wide limits. For the control of a single 100 K.W. alternator, however, many times the power available in a microphone is required. However, the power required for modulating the output of such an alternator is, perhaps, not over 1% of the total output, and this is a tremendous improvement over the ordinary absorption method.

Mr. Amy's modulator is supposed to operate on a very similar principle, but it is probable that it is as much a loss device as a reactance device. It consists, I am told of an iron core having an exciting winding which carries the voice currents and a winding which carries the power currents of the antenna circuit. The resistance and reactance of the antenna circuit winding depends on the flux in the core, and this flux is caused to vary with the voice currents. Thus the device becomes a rather hybrid absorption and reactance device and one in which the equality of power capacities does not hold very precisely.

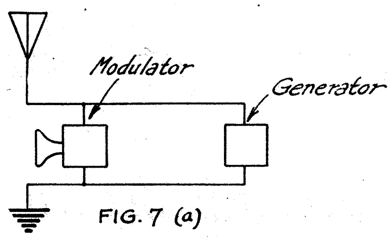
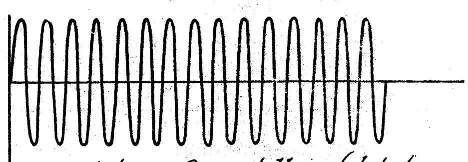
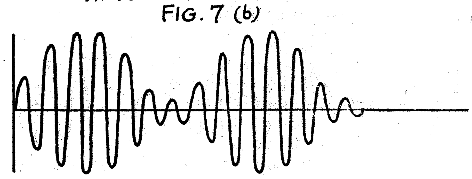



FIG. 7 (a)



Antenna Current-Unmodulated
FIG. 7 (b)



Antenna Current-Modulated
FIG. 7 (c)

It is conceivable that a scheme might be worked out whereby the reactance method of control may be used and the ratio of the power required to operate the modulator to the power which it will modulate made smaller than in either of these devices. It is along this line that the efforts of the experimenter should be directed. With the development of the high-power vacuum tubes now available and the special circuits and special equipment for their operation now developed, there still remains the problem of simple and efficient modulation. Until this problem is solved it is doubtful whether long distance radio telephone communication will be successfully accomplished.

The power-control methods, while the most commonly used, were the last to be developed, and the most effective of them are those which are applicable to the vacuum tube generator. The tube because of its inherent amplifving characteristics suggests immediately the possibility of the control of large values of power by the use of comparatively small amount of power. In this connection the grid circuit suggests itself most forcibly for use in modulation, since this circuit is one of high impedance, very high in fact, and is furthermore a circuit in which the voltage which will reduce the power in the antenna circuit from its maximum to zero causes very little current to flow and consequently very little power to be dissipated. The objection to this method of modulation lies in the fact that it is very critical in adjustment, and also that great distortion is likely to take place unless extreme care is used in making adjustment.

Mr. Kischpaugh in his paper before the Radio Club of America some time ago showed characteristic curves which make this point very well. This is shown in Fig. 8. The grid voltage is plotted against the antenna current, and shows a rather slowly varying antenna current for high values of the grid voltage, and a very sharp dropping off of this current for lower values of this potential. It is evident that with the grid biased to make its mean voltage that of the point "c", the change in the antenna current will be small for a given voice voltage applied to the grid. On the other hand, for a mean grid voltage somewhere between "a" and "b" on the curve, the change in antenna current will be large for a given change in the grid potential. In addition there is very little power required for modulation when the grid is fixed at this latter potential, since the more negative the grid the less current and consequently the less the power required for modulation.

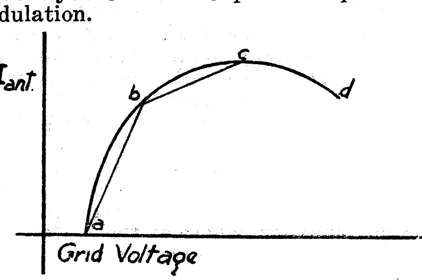



FIG. 8

Unfortunately, however, minor variations of the constants of the antenna or local circuit will destroy any adjustment which is obtained in the grid circuit, and only by constant readjustment can the circuit be kept in such condition that modulation is effectively accomplished. In addition to this, experience shows that with the usual care in adjustment which is given by the amateur to his transmitter, the grid-modulation circuit usually results in very serious distortion.

These then are the objections which militate against grid modulation. It has been used quite successfully and it appears that certain commercial companies are now planning on its use, but general experience indicates that some more reliable and easily adjustable method is essential.

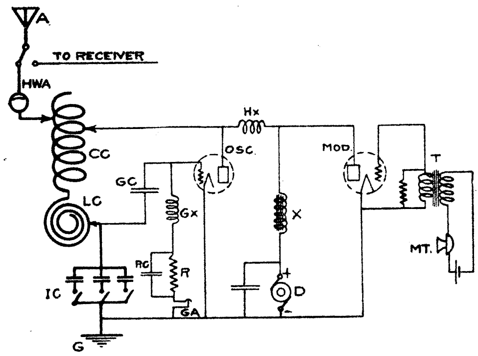



FIG. 9

The second modulation scheme that is in common use is the so-called "constant current" scheme or plate circuit modulation. This scheme is shown in Fig. 9, and this is the one with which we are probably most familiar. It may be considered either an absorption method or a power control method, depending on whether the modulator tube is viewed as part of the power supply or part of the generating circuit. This circuit operates by changing the *voltage* on the plate of the oscillator. This is accomplished by changing the current thru the modulator by means of changes of the grid potential of the modulator tube. Because of the fact that the output power is reasonably proportional to the voltage on the plate of the oscillating tube, and this in turn varies with the voltage on the grid of the modulator tube, we have a scheme in which (when sufficient filament emission is available) distortion is not a serious factor, and one in which the adjustment is not seriously critical. Its outstanding advantage lies in the fact that the adjustments which are required for best modulation are in the main independent of the adjustments of the generating circuit. For this reason, if there were no other reason, it is to be preferred to the grid modulation scheme.

In closing, let me say that this segregation of adjustments or of control is the characteristic which differentiates all effective and easily-usable radio schemes and apparatus from the less usable types and that in any radio equipment which is to be successful, whether it be a radio telephone transmitter, an amplifier, a receiver, a loud speaker, or what not, the aim of the experimenter should be not only to make the most highly effective device but also to make one in which the various factors that go to make operation successful are separately controllable. This should be done even at a slight sacrifice of efficiency. If it is successfully carried out, the average efficiency of operation will be greatly increased over that of a device which is capable of much higher absolute efficiency but which requires infinitely careful adjustment because of the fact that its controls vary more than one factor at a time.