A Course in Radio Fundamentals

Lessons in Radio Theory for the Amateur

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No. 6—Modulation

The present installment deals with various methods for modulating a radio-frequency carrier. The experimental work consists in determining the modulation characteristics of r.f. amplifiers, using the point-by-point method, under different conditions of operation. The influence of various factors on the linearity of a modulated amplifier is the chief subject investigated.

Contrary to what might be anticipated, the experiments outlined do not involve actual modulation of a carrier. Such modulation would require additional equipment to that already specified for the series, and under present conditions components of any kind — and particularly audio transformers — are extremely difficult to obtain. It is also a fact that, unless an oscilloscope is available for depicting actual operation with modulation, the use of a modulating signal would add comparatively little to the instructional value of the experiments. Those who do have an oscilloscope and an audio amplifier suitable for modulating the experimental amplifiers can, of course, extend the work. The obvious direction for such an extension to take is in comparing oscilloscope patterns with the performance curves obtained as described in the experiments.

ASSIGNMENT 20

Study *Handbook* Sections 5–1, 5–2 and 5–3, beginning page 84. Perform Exps. 31 and 32.

Questions

1) What is meant by the term "modulation"?

2) What is the function of the microphone in a radiotelephone system?

3) Name the three fundamental methods of modulating a radio-frequency current.

4) What is the "carrier"?

5) In present-day practice, what requirements must be met by the carrier in radiotelephone transmission on communication frequencies?

6) Why is a "buffer" amplifier necessary?

7) Define percentage of modulation.

8) What is meant by "linearity" of a modulated amplifier?

9) Define modulation capability.

10) An unmodulated carrier produces a current of 2.5 amperes in an antenna system. When modulation is applied it is found that the maximum instantaneous amplitude of the current is 4.3 amperes. What is the percentage of modulation, assuming that the modulated amplifier is linear?

11) What is the ratio of average power in a 100 per cent amplitude-modulated wave to the power in the carrier alone, assuming sinusoidal modulation?

12) What is meant by the term "modulation envelope"?

13) What are sidebands?

14) If the modulation applied to a carrier is unsymmetrical, how should the modulation percentage be computed?

15) Describe overmodulation. Why should overmodulation be avoided?

16) A 3900-kc. carrier is modulated by a sinusoidal signal having a frequency of 1600 cycles. What are the sideband frequencies?

17) The audio-frequency output of the modulator of a certain radiotelephone transmitter contains substantially no audio frequencies higher than 4200 cycles. What channel width is required for the modulated output of the transmitter?

18) A transmitter is modulated by a 1000-cycle tone which has pronounced harmonics up to the fifth. If the carrier frequency is 28,650 kc., what are the frequency limits of the channel occupied by the signal?

19) What are spurious sidebands?

20) Name three systems used for amplitude modulation.

21) What is the average ratio of power in speech waveforms to power in a sine wave? How does this affect the required power capacity of the modulator, when plate modulation is used?

22) Define modulating impedance of a Class-C plate-modulated amplifier.

23) A Class-C amplifier is operating at a plate voltage of 2000 and is adjusted so that the plate current is 150 milliamperes. How much audio power is required for plate modulation of the amplifier. for a modulation percentage of 100, assuming that the modulating signal is sinusoidal?

24) What is the modulating impedance of the amplifier in Question 23?

25) Draw a circuit diagram showing plate modulation of a neutralized triode Class-C amplifier, using a Class-B modulator.

26) An amplifier having an audio-frequency power output of 130 watts is available for plate-modulating a transmitter. If the modulation is to be 100 per cent, what is the maximum possible power input to the Class-C modulated amplifier?

27) How can the power input to a Class-C plate-modulated amplifier be adjusted to the proper value for 100 per cent modulation?

28) How may plate modulation be applied to a tetrode or pentode Class-C amplifier? Draw a circuit diagram.

29) Describe the method of using choke coupling between the modulator and modulated amplifier. Why is this system seldom used?

30) Does the d.c. plate current of a properly-operating Class-C amplifier change when the amplifier is plate modulated? Why?

31) A screen-grid Class-C plate-modulated amplifier operates under the following conditions; plate voltage, 2500 volts; plate current, 125 ma.; screen voltage, 400 volts; screen current, 30 ma. If the screen current is to be taken from the plate supply, what value of screen dropping resistor is required, and what is the modulating impedance of the amplifier? How much audio power is necessary for 100 per cent modulation?

32) Why is it necessary to neutralize a triode amplifier as completely as possible when the amplifier is to be modulated?

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33) Describe the general operating conditions necessary if a Class-C amplifier is to have a linear modulation characteristic.

ASSIGNMENT 21

Study *Handbook* Sections 5-4 and 5-5, beginning page 88. Perform Exp. 33.

Questions

1) What are the advantages and disadvantages of grid-bias modulation as compared with plate modulation?

2) Describe the essential principles of the grid-bias modulation system.

3) Why should the source of fixed bias used with a grid-bias modulated amplifier have low internal resistance?

4) A tube having a rated plate dissipation of 80 watts is to be used as a grid-bias modulated amplifier. What is the approximate carrier power output obtainable? How much power could be secured from the same tube if plate modulation was used?

5) In a grid-bias modulated amplifier, what is the effect on linearity of adjusting for too-high carrier efficiency?

6) Draw a circuit diagram of a Class-C amplifier arranged for grid-bias modulation.

7) Describe the operating principles of suppressor-grid modulation. How does this method compare with grid-bias modulation?

8) Why is it necessary that the r.f. stage driving a grid-bias modulated amplifier have good output-voltage regulation? How can good regulation be secured?

9) Describe a method of adjusting a grid-bias modulated amplifier for proper operating conditions.

10) Why should the d.c. plate current of a properly-operated grid-bias modulated amplifier be constant under modulation? What is the permissible tolerance in this respect? Is constant plate current a certain indication that the amplifier is operating linearly?

11) What is the effect of load resistance on the carrier power output obtainable from a grid-bias modulated amplifier, assuming that the amplifier is adjusted for linear operation?

12) What is the effect of excitation voltage on the linearity of a grid-bias modulated amplifier, assuming that load resistance, d.c. grid-bias voltage, etc., are fixed?

13) Explain the operating principles of cathode modulation.

14) Two tubes each having a plate dissipation rating of 60 watts are to be used in push-pull as a cathode-modulated amplifier. If a modulator having an audio-frequency power output of 80 watts is available, what is the maximum carrier output power obtainable if the modulation percentage is to be 100 per cent? If the plate voltage on the modulated amplifier is 1500, what is the modulating impedance?

15) How should a cathode-modulated amplifier be adjusted for linear operation?

ASSIGNMENT 22

Study *Handbook* Sections 5-6, 5-7, 5-8 and 5-9, beginning page 91.

Questions

1) Why is a Class-B type audio amplifier generally used for plate modulation of a Class-C amplifier?

2) Why is it necessary to have good regulation of the output voltage of the stage driving a Class-B amplifier?

3) What design precautions should be taken to ensure good output voltage regulation of the driver stage?

4) A Class-C amplifier taking a plate current of 180 ma. at a plate voltage of 1250 is to be plate modulated. How much audio-frequency power is required? If the Class-B modulator requires a plate-to-plate load of 10,000 ohms, what is the proper turn ratio of the coupling transformer, assuming that the transformer losses are negligible?

5) Why is it necessary to use a voltage source having low internal resistance to supply grid bias for a Class-B amplifier?

6) Is it safe to operate a Class-B modulator without load?

7) What is the result of overdriving a Class-B modulator?

8) What requirements should be met by the plate supply for a Class-B modulator?

9) What is meant by the terms "sensitivity" and "frequency response" when used in connection with microphones?

10) Describe the principle of operation of four types of microphones and show suitable circuits for connecting them to an amplifier.

11) About what order of output voltage can be expected from a crystal microphone under normal conditions — that is, speech of average intensity — from single-button carbon, double-button carbon, and velocity microphones, when provided with appropriate coupling transformers?

12) What is meant by "stage gain"?

13) What is the general function of a speech amplifier in a modulation system?

14) Why is resistance coupling generally used in voltage-amplifier stages? Under what conditions is resistance coupling inapplicable?

15) What determines the frequency response characteristic of a resistance-coupled amplifier? Over what frequency range is it necessary to have "flat" amplification for satisfactory speech transmission?

16) What is a decoupling circuit, and why is it used?

17) What considerations determine the point in the circuit at which the gain control is placed?

18) An amplifier is to deliver an audio power output of 2 watts when excited by a crystal microphone having a peak output voltage of 0.02 volts with normal speech. Using the tube characteristic tables and the data in Table I, page 97, of the *Handbook*, select a suitable tube line-up and draw a circuit diagram, marking proper values on the components. Indicate proper plate voltages on the circuit diagram.

19) Describe the operation of a phase inverter. For what purpose is such a circuit used?

20) What precautions should be taken to minimize hum in a speech amplifier?

ASSIGNMENT 23

Study *Handbook* Section 5-10, beginning page 98. If an oscilloscope is available, use it in conjunction with Exps. 31, 32 and 33, making connections as described in the *Handbook*. Compare the oscilloscope patterns with the data obtained by measurement and plotted graphically. A suitable modulating voltage must be available for this purpose; 60-cycle a.c. will be quite satisfactory if the voltage can be adjusted to the proper value. A transformer having suitable turns ratio should be used between the modulated amplifier and the 115-volt a.c. line.

Questions

1) What is the difference between the "wave-envelope" and "trapezoidal" patterns used in checking modulation?

2) What connections are necessary between the transmitter and oscilloscope to obtain the wave-envelope pattern?

3) Show a method of connecting the oscilloscope and transmitter for securing a wedge pattern. What precautions are necessary in making these connections?

4) How can percentage of modulation be measured with the oscilloscope?

5) If the voice waveform is found to be unsymmetrical, what can be done in the speech amplifier to insure that "splatter," or spurious sidebands, will be minimized on occasional voice peaks which cause overmodulation?

6) Why is it frequently desirable to connect a tuned circuit to the vertical-plate terminals of the oscilloscope, coupling through a link circuit to the transmitter?

7) In using the wedge pattern, from what part of the audio system should the audio voltage for the horizontal sweep be taken?

8) How can the oscilloscope be used to check the linearity of a 'phone transmitter? Which type of pattern is preferable?

9) If indications of a carrier appear on the oscilloscope screen when the plate current of the modulated amplifier is completely cut off but the transmitter is otherwise operating, what are the possible causes?

10) What is the effect on the modulation pattern of the presence of a radio-frequency voltage on the horizontal plates of the oscilloscope? What can be done to prevent such a voltage from reaching the horizontal plates?

11) Describe a method of checking for spurious sidebands.

12) Name some possible causes for an upward shift in plate current with plate modulation; with grid-bias modulation.

13) If the carrier is found to have excessive hum modulation, how can the cause of the hum be localized?

14) What is the common indication of the presence of r.f. in the audio system? What precautions are necessary to prevent such r.f. pickup?

15) Name some possible causes of a downward shift in plate current with plate modulation; with grid-bias modulation.

ASSIGNMENT 24

Study *Handbook* Sections 5–11 and 5–12, beginning page 102. Perform Exp. 34.

Questions

1) How does frequency modulation differ from amplitude modulation?

2) Define frequency deviation and deviation ratio.

3) In what two respects does frequency modulation have distinct advantages over amplitude modulation? What is the chief disadvantage of frequency modulation from a practical communication standpoint?

4) Explain why a large deviation ratio gives an improvement in signal-to-noise ratio as compared to a low deviation ratio.

5) Why is a frequency modulation system less sensitive to natural static and other electrical noises than an amplitude modulation system?

6) Describe the operating principles of a simple type of reactance modulator.

7) What is meant by the "sensitivity" of the modulator?

8) A reactance modulator used in conjunction with an oscillator adjusted to a mean or carrier frequency of 3.58 megacycles is capable of causing the frequency to deviate linearly 1 kc. on either side of the carrier. If the output of the transmitter is to be in the 56-Mc. band, what is the output carrier frequency, and the output frequency deviation? What is the deviation ratio if the upper limit of audio frequencies to be transmitted is 4000 cycles?

9) What is meant by linearity of a frequency modulation system?

10) Why is it desirable to stabilize the d.c. voltages applied to a reactance modulator and its associated oscillator?

11) An f.m. transmitter to operate on 112.6 Mc. is to have a deviation ratio of 5, based on an upper audio frequency imit of 4000 cycles. If the oscillator and reactance modulator are to be operated in the 7-Mc. band, over what frequency range should the modulator operate linearly? What is the maximum frequency deviation required at the fundamental frequency?

12) What is the effect on the sensitivity and linearity of a reactance modulator of varying the circuit constants of the r.f. voltage divider across the oscillator tank circuit?

13) Describe a method of using a selective receiver to check frequency deviation of a reactance-modulator system.

14) What is the effect on linearity of excitation voltage and plate-circuit loading in the r.f. stages of a frequency-modulation transmitter?

15) How do the sidebands generated by frequency modulation compare with those set up in amplitude modulation?

EXPERIMENT 31

Plate Modulation Characteristic of Class-C Amplifier

Apparatus: The circuit diagram for this experiment is shown in Fig. 1. Equipment required includes the power supply, bias supply, crystal oscillator, tube board, circuit board, vacuum-tube voltmeter, and multi-range test instrument. A neutralized amplifier circuit similar to that shown in Exp. 30 is used. The grid circuit of the amplifier is coupled through the 100-$\mu\mu$fd. fixed condenser to the plate tank circuit of the oscillator. Bias for the amplifier is taken from the bias supply through the 2.5-millihenry r.f. choke, *RFC*. L_1 is the fixed coil on the circuit board, with 30 turns in use; the plate voltage lead is tapped on the coil at the 15th turn. C_1 is the 250-$\mu\mu$fd. condenser on the circuit board and C_2 is the small condenser (about 50 $\mu\mu$fd. maximum capacity) used in this case as a neutralizing condenser. In wiring the amplifier circuit keep the leads as short as the physical conditions permit, and use enough separation between the crystal oscillator and the amplifier tank circuit, C_1L_1, to reduce the inductive coupling between the two to a negligible amount.

The v.t. voltmeter is inductively coupled to the amplifier tank circuit through the movable coil, L_2, from the circuit board. Place the coil so that it is not intimately associated with the amplifier wiring. To do this it will probably be necessary to remove it from the circuit board entirely, setting it up off the board so that it can be coupled to the outer end of L_1 (assuming that the construction illustrated in Fig. 8, page 67, August *QST*, is used).

Separate milliammeters and voltmeters are shown in Fig. 1, but, as in the previous experiments, the single test kit can be used for all measurements if provision is made for closing those circuits through which current must flow — the amplifier grid-bias circuit and d.c. plate circuit — when the instrument is used elsewhere. Plate voltage measurements should be made with the highest-range scale which will give reasonably precise readings — at least a 500-volt scale.

For the resistor *R* shown in the diagram use 1-watt "carbon" resistors having values of 5000 and 10,000 ohms. Ordinary wire-wound resistors cannot be used. The two resistors may be connected in series to give a total resistance of 15,000 ohms. These three values will suffice for the experiment.

In using the plate power supply in this experiment, set the variable resistor (R_5, Fig. 4, page 65, August *QST*) to give maximum output voltage; that is, so that none of the load current flows through it. The currents to be drawn exceed the safe ratings of the ordinary small volume-control type wire-wound resistors. Sufficient voltage variation can be secured by means of the output taps.

Procedure: The purpose of this experiment is to show, on a small scale, the effect of load resistance on the linearity of a plate-modulated Class-C amplifier. Since the output voltage of the power supply is limited to somewhat less than 400 volts, it will be assumed that this voltage is the maximum that would be applied to the Class-C amplifier at the modulation peak. The plate voltage for the carrier alone therefore will be one-half this value, or 200 volts.

As explained in the *Handbook*, the plate efficiency of a plate-modulated Class-C amplifier must remain constant throughout the modulation cycle — that is, over the com-

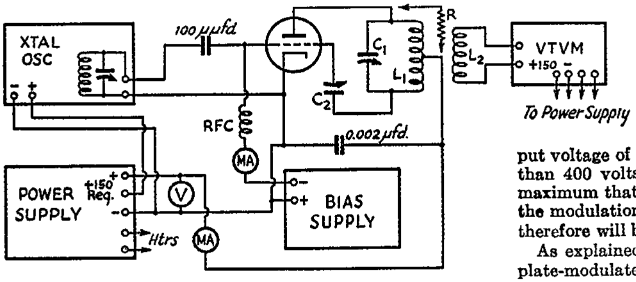

Fig. 1

plete range of plate voltage from zero to twice the carrier plate voltage — if the amplifier is to be modulated 100 per cent. To meet this condition, it is necessary that the operating angle of the amplifier be not greater than 180 degrees at the modulation peak, since the plate efficiency decreases rather rapidly when the operating angle is increased beyond 180 degrees. Therefore the grid bias must be at least the value which will give plate-current cut-off, under static conditions, at the *peak* plate voltage. This accounts for the customary rule that the grid bias for a Class-C amplifier should be "twice cut-off" at the carrier plate voltage. (In practice it is more likely that the grid bias would be set to a value which gives an operating angle of 150 degrees or less under carrier conditions, as described in *Handbook* Sec. 4–8. This leads to a grid bias value considerably larger than twice cut-off if the tube has a fairly high μ, but gives higher plate efficiency.) Using a 6J5 as an amplifier, the minimum grid bias required is approximately 400/20 (E_b/μ) or 20 volts. To be on the safe side a little higher bias, say 25 volts, may be used.

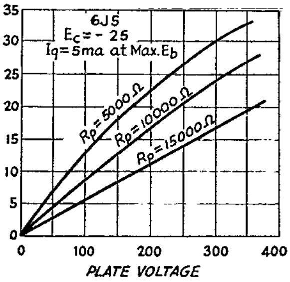

Fig. 2

Set the bias to approximately 25 volts, disconnect the d.c. plate voltage lead to the amplifier, and apply power to the crystal oscillator, using the 150-volt regulated tap as the plate supply. Neutralize the amplifier circuit by one of the procedures described in Exp. 29, having first adjusted the oscillator output (by means of the oscillator tank condenser) to give an amplifier grid current between 5 and 10 milliamperes. Neutralize as completely as possible. If reasonable care has been used in separating the oscillator and amplifier tank circuits there should be no difficulty in neutralizing well enough so that the grid current will show no more than a barely perceptible change as the amplifier plate condenser is tuned through resonance. After neutralizing, apply plate voltage to the amplifier and set the plate tank condenser to resonance, as indicated by the setting which gives minimum plate current.

Now connect the 15,000-ohm load resistance between the "B+" tap and the plate of the amplifier tube as shown in Fig. 1. Set the plate voltage to the maximum available, check the setting of C_1 for resonance, adjust the oscillator tank condenser to give an amplifier grid current of 5 milliamperes, and then adjust the coupling between L_2 and L_1 so that the v.t.v.m. reads nearly full scale on its lowest range. All 35 turns of the coil L_2 may be used. Once the proper coupling is found, do not disturb the two coils during a run.

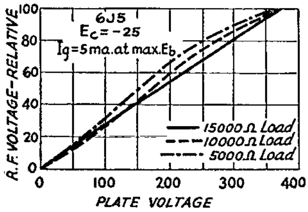

Fig. 3

Take the following readings: plate current, grid current, plate voltage, and v.t.v.m. current. Change the plate voltage to the second tap and repeat, continuing in this way until readings have been taken at all five taps (or at intervals of 50 to 75 volts in case a different type of power supply than that described in August *QST* is used; in such case the maximum plate voltage should be limited to 350 or 400 volts). Change the load resistance, *R*, to 10,000 ohms and repeat, then take a similar set of data once more with 5000 ohms at *R*. In each case adjust the grid current to 5 milliamperes with the highest plate voltage on the amplifier and with the plate tank circuit tuned to resonance.

When the load resistance is lowered the r.f. plate voltage will decrease, hence the v.t.v.m. readings will be smaller. The coupling between L_2 and L_1 may be increased to compensate for this drop in voltage, if desired; the readings are only relative and the values for different runs need not be compared. When the data have been obtained, plot the plate current against plate voltage as shown in Fig. 2, drawing a smooth curve through each set of points. Fig. 2 is a typical set of curves taken on a 6J5, and Fig. 3 shows the corresponding variation of r.f. output voltage, plotted in terms of percentage of the maximum value in each case. The curves do not all end on the same ordinate because the maximum plate voltage was subject to small variations with changes in the plate current taken by the amplifier with different load resistances. The d.c. calibration of the v.t. voltmeter may be used for obtaining the relative r.f. voltages. Similar plots could be made of the rectified grid current; it will be observed that the grid current rises as the plate current falls, for the reasons explained in Exp. 30.

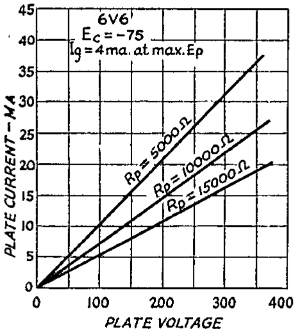

Fig. 4

These curves show the behavior of d.c. plate current and r.f. output voltage with varying plate voltage, and hence show how the amplifier will operate with plate modulation. For distortionless modulation the plate current and r.f. output voltage should be directly proportional to the plate voltage; that is, the curves showing the relationship between these two quantities and plate voltage should be straight lines. With the particular tube used in these tests the "modulation characteristic," as such a curve is called, is linear (straight) with the 15,000-ohm load resistance, but shows curvature with the lower values of load resistance. In each case the r.f. output voltage, shown in Fig. 3, has approximately the same shape as the corresponding plate-current curve.

The modulation characteristic must be linear for distortionless modulation for the same reason that the grid voltage-plate current characteristic of an amplifier tube must be linear (Exp. 23, Fig. 11). If the modulation characteristic is not linear, the envelope of the modulated wave will not be a true reproduction of the audio-frequency voltage applied to the plate circuit of the modulated amplifier, hence distortion will be introduced in the modulation process. In addition, the relationship between plate voltage and d.c. plate current must be linear so that the modulator can work into a constant load resistance. The load resistance represented by the Class-C amplifier is equal to the slope of its plate voltage-plate current curve and is measured as described in the introduction to Installment 4, September *QST*. Since the slope, and hence the resistance, is constant only when the modulation characteristic is straight, a curved characteristic indicates that the load resistance varies over the audio-frequency cycle. In Fig. 2 the slope at the lower end of the 5000-ohm curve is more than twice as great as at the upper end, which means that the load resistance into which the modulator works varies in a ratio of more than 2 to 1 over an audio cycle, when the amplifier is modulated 100 per cent. Since the audio output voltage of the modulator depends upon the value of load resistance into which the modulator is delivering power, a load resistance which varies will cause the waveshape of the modulator output voltage to differ from the waveshape of the signal applied to its grid Hence, even though a curved Class-C amplifier plate voltage-plate current characteristic could conceivably result in a fairly straight-line relationship between plate voltage and r.f. output voltage (if the plate efficiency of the Class-C amplifier should vary in such a way as to compensate for the curvature) nevertheless distortion would be introduced because of the varying load on the modulator.

The curvature of the characteristics in Fig. 2 for loads of 10,000 and 5000 ohms is chiefly the result of insufficient cathode emission. That is, the tube is being worked beyond its capabilities at the lower values of load resistance, where the peak currents reach high values. This can be shown by substituting a tube having a cathode which takes more power. There is no octal-based triode of heavier construction comparable to the 6J5 in general characteristics, but a 6V6 can be used by connecting its screen and plate together to make the tube into a triode. The amplification factor in this case is approximately 6 (this can be determined by measurement, using the procedure outlined in Exp. 22), so that for plate current cut-off at the highest plate voltage available the fixed bias on such a tube should be at least 400/6, or 67 volts. The curves of Fig. 4 were taken on such a tube, using the procedure described above but with the grid bias set at 75 volts (slightly above cut-off) and the grid current adjusted by means of the oscillator plate tank condenser to 4 milliamperes when the tube was operating at maximum plate voltage. The curves are straight lines, showing that this particular tube is capable of maintaining a linear relationship between input and output under conditions which resulted in considerable non-linearity when the 6J5 was used. The r.f. output voltage should be plotted in the same way as in Fig. 3, when it will be found that the curves are practically straight lines.

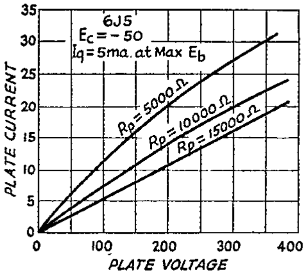

Fig. 5

EXPERIMENT 32

Effect of Grid Bias and Excitation Voltage on Linearity

Apparatus: Same equipment and set-up as in Fig. 1, Exp. 31.

Procedure: In this experiment the investigation of the factors affecting the linearity of a plate-modulated Class-C amplifier is continued. Using the 6J5 as an amplifier tube, set the grid bias at approximately —50 volts and repeat the measurements described in Exp. 31. Plot the data in the same form as in Exp. 31. Fig. 5 shows the results of such measurements. It can be observed that there is no marked improvement in linearity at the lower values of load resistance as compared to the curves shown in Fig. 2 for a grid bias of —25 volts.

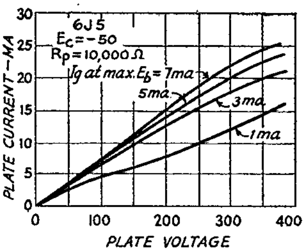

Fig. 6

Using a load resistance of 10,000 ohms and a grid bias of —50 volts, adjust the grid current to 7 milliamperes with the amplifier tube operating at the highest plate voltage, check the amplifier tank circuit tuning to make sure it is at resonance, and again measure plate current, plate voltage, grid current and r.f. output voltage as the plate voltage is decreased one tap at a time on the power supply. When the run is complete, repeat the procedure with the grid current set to 3 ma., and then repeat once more with the grid current set at 1 ma. with the amplifier operating at the highest plate voltage. Plotting the plate voltage — plate current data should give a set of curves resembling those of Fig. 6, taken on a 6J5 in such an experimental set-up. Increasing the amount of excitation, as measured by the d.c. grid current, improves the linearity, particularly at the higher plate voltages. The curves for a grid current of 1 milliampere does not conform to what might be expected from an inspection of the other three curves; the tendency for the slope of the curve to rise rather than to continue decreasing at the higher plate voltages is chiefly the result of a small amount of regeneration attributable to less-than-complete neutralization. In this case the grid current did not show the usual increase with decreasing plate voltage but was practically constant over the whole range of plate voltage. This regenerative effect is masked in the other curves because in those cases the regenerative voltage is small in comparison to the driving voltage from the oscillator.

The effect of improper grid bias can be demonstrated by using the 6V6, connected as a triode with the screen grid and plate tied together. As explained in Exp. 31, the grid bias required for plate-current cut-off at a plate voltage of 400 is approximately —67 volts. Using a bias of —75 volts, follow the same experimental procedure and take the same data as before, then repeat with the bias set at —100 volts. Finally, set the bias to about —33 volts, the cut-off value for a plate voltage of 200, so that the amplifier is operating

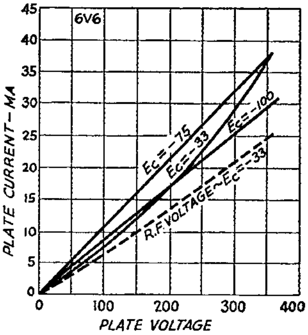

Fig. 7

Class-B under carrier conditions, and repeat the measurements. Fig. 7 shows a set of curves obtained in this way. The curve for $E_c = -75$ is straight, as is also the curve for $E_c = -100$. The grid currents at maximum plate voltage were 4 and 2 milliamperes, respectively, for these two curves.

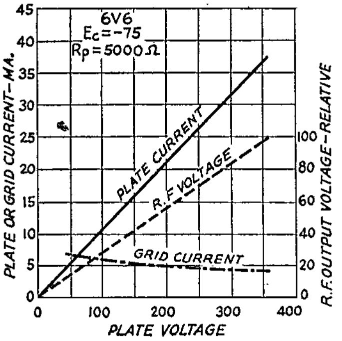

Fig. 8

With a bias of —100 volts a grid current of 2 ma. was approximately the maximum obtainable from the oscillator under the conditions of the experiment. The curve for —33 volts was taken with the grid current set at 4 milliamperes at the maximum plate voltage.

With the bias set at —33 volts the amplifier operates under conditions intermediate between Class B and Class A when the plate voltage is above 200 volts. Thus the plate efficiency shows a marked decrease as the plate voltage increases. However, the amplification ratio increases as the Class-A condition is approached, so that the r.f. output voltage curve is quite straight. Nevertheless, the nonlinearity of the plate voltage — plate current curve would introduce considerable distortion in such a system because of the variation, with plate voltage, of the load resistance represented by the Class-C amplifier plate circuit. The effect of such variation on the modulator operation was described in the preceding experiment.

As shown by the curves, once the bias is at the cut-off value for the maximum plate voltage to be applied to the tube under modulation, the modulation characteristic of the amplifier will be quite linear provided the excitation voltage is large enough. Increasing the bias beyond this value will improve the efficiency and may also improve the linearity. The latter effect is too small to show on the graphs, but was detectable in the measurements. Fig. 8 shows the result of choice of suitable operating conditions with a tube having ample cathode emission. Notice that the grid current varies as the plate voltage is changed, for the reasons explained in connection with Exp. 30. This same variation will occur during an audio modulating cycle, so that the load on the driving stage also varies when the Class-C amplifier is modulated. This audio-frequency variation of driver loading is one reason why it is desirable to use a buffer amplifier between the oscillator and modulated amplifier, since a change in load will usually cause some shift in oscillator frequency and hence frequency modulation will occur if the modulated amplifier is excited directly by the oscillator.

EXPERIMENT 33

Grid-Bias Modulation Characteristics of Class-C Amplifier

Apparatus: The equipment and circuit arrangement are the same for this experiment as for Exps. 31 and 32, except that the voltmeter is transferred to the grid bias supply.

Procedure: The object of this experiment is to determine suitable operating conditions for grid-bias modulation of a Class-C amplifier. With this type of modulation the plate efficiency and d.c. plate current both are varied in accordance with the modulating voltage, but the d.c. plate voltage is constant. At the modulation peak the amplifier should reach its maximum plate efficiency and the d.c. plate current should be twice the carrier value of plate current. The amplifier can be adjusted for normal Class-C efficiency (about 70 per cent) at peak modulation; the operating angle therefore should be 180 degrees or less (grid bias at cut-off or higher) at the modulation peak. The minimum bias under modulation, at the instant when the modulating signal has its maximum positive value, therefore should not be less than the cut-off value for the tube and plate voltage used.

The 6J5 is a suitable type of tube for use in the experiment. The plate voltage should be the maximum available from the power supply — between 350 and 400 volts. At this plate voltage the negative grid bias required for plate-current cut-off is approximately 400/20 (E_b/μ), or —20 volts. Because of the tendency of the amplification factor of the tube to decrease near the cut-off point it is more satisfactory to use —25 volts as the cut-off value. The taps on the bias supply should be adjusted to give steps of 10 to 15 volts, starting with 25 volts and going to higher values. An additional slider tap on R_2 (Fig. 2, page 56, July *QST*) should be provided; it may be borrowed temporarily from R_3 since the taps on the latter resistor will not be needed. Two voltages will be available from each tap by setting R_4 either at minimum or maximum. The following represents a typical series of bias voltages obtainable by suitable settings of the taps on R_2: 25, 30, 35, 40, 57, 64, 75, 92. The first voltage is obtained by setting the clip on the lower end of R_2, the latter by setting the clip on the upper end to secure the full output voltage of the bias supply. The variation in voltage provided by R_4 at the two last taps is quite small, so it is sufficient to set R_4 at maximum in these two cases.

The measurement procedure is similar to that used in Exps. 31 and 32, except that the plate voltage is fixed and the grid bias is varied. First measure the plate voltage, then set the bias at approximately 25 volts, adjust the oscillator tuning to give a d.c. grid current of 10 ma., and measure the plate current, grid current, and v.t. voltmeter current. Adjust the coupling to the v.t. voltmeter to give nearly a full-scale reading on the low range. Then increase the bias one step at a time, recording the readings at each step as above, until the plate current is reduced to zero. Use the 10,000-ohm 1-watt resistor as a load, and before starting the series of measurements tune the plate tank circuit of the amplifier to resonance, as indicated by minimum plate current. The readings should be taken fairly quickly, since the load resistor will overheat at the lower values of grid bias. As in the previous two experiments, set the variable resistor in the power supply so that the output voltage is maximum — that is, so that no part of the resistor is in the load circuit of the power supply.

When the measurements are completed, take a new set with an initial d.c. grid current of 8 milliamperes, then take similar sets with initial grid currents of 6 and 4 milliamperes. Plot the measured data against grid bias voltage. A typical set of such curves is shown in Figs. 9, 10, 11 and 12. These show the effect of excitation voltage, as indicated by the value of grid current for a given bias voltage, on the input, linearity and grid bias. In each of these cases the values at minimum grid bias (approximately —25 volts) can be taken as representing conditions existing at the modulation peak. For carrier conditions the bias would be set midway

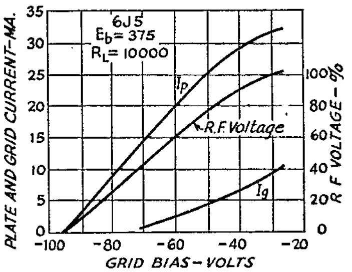

Fig. 9

between the minimum bias and that required to cut off plate current completely; for example, in Fig. 11 the plate-current curve reaches the zero axis at a bias of −70 volts; the difference between this and the minimum bias (−25 volts) is 45 volts, which represents the total voltage swing required from the modulator for 100 per cent modulation. Half of 45 volts, or 22.5 volts, is the peak value of the modulating voltage on one side of its axis, and since the minimum instantaneous grid bias must not be less than the static cut-off value, this amount of voltage must be added to the cut-off bias to find the operating bias under carrier conditions. The carrier operating bias therefore would be 25 + 22.5, or −47.5 volts. At this bias the plate current is 13 milliamperes — half of the maximum value, which occurs at the minimum bias of −25 volts.

The r.f. output voltage at $E_c = -47.5$ also is half its maximum value, so that the power output (which is proportional to the square of the r.f. voltage) is ¼ its maximum value. Since the d.c. plate voltage is constant, the d.c. plate power input is half its maximum value (375 × 0.013 compared to 375 × 0.026). The proportionally greater reduction in power output therefore must be the result of a decrease in plate efficiency; in fact, the efficiency must have decreased to half its value under maximum conditions.

If the same value of fixed grid bias, −47.5 volts, is used for carrier conditions with other values of excitation voltage, serious distortion will result. In Fig. 9, for example, this value of bias would give a carrier plate current of 25 milliamperes. If the modulating voltage swings the instantaneous bias plus and minus 22.5 volts about the carrier bias (the conditions of operation which give 100 per cent modulation in the case of Fig. 11) the modulation peak will occur at −25 volts and the valley at −70 volts. The grid bias-plate current characteristic is badly curved in the peak region, hence the modulated wave will be distorted. Also, the plate currrent and r.f. voltage do not go to zero at 70 volts bias, hence the modulation is less than 100 per cent. The same state of affairs exists in Fig. 10, although to a lesser extent. In Fig. 12, the same carrier bias and modulating voltage would result in overmodulation, since the plate current is zero at approximately −65 volts bias. Hence a negative swing to −70 volts would completely cut off the output for an appreciable period of time, giving a modulated wave of the type shown in Fig. 502 in the *Handbook*. It is evident, therefore, that for a given value of carrier bias and a specified modulating voltage, there is, in general, only one value of excitation voltage which will permit linear 100 per cent modulation. This is subject to the further restriction that the peak positive swing of the modulating voltage should not cause the instantaneous grid bias to reach a value lower than that necessary to cut off the plate current (without excitation). This restriction is necessary because bias less than cut-off would increase the operating angle to more than 180 degrees, with the result that at the modulation peak the plate efficiency would not be increasing at the proper rate. In grid bias modulation the efficiency must reach its highest value at the modulation peak.

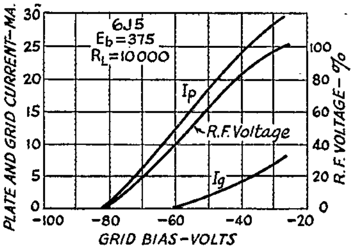

Fig. 10

Further inspection of the curves of Figs. 9–12 shows that, with the same tube and plate voltage, a large number of operating conditions all capable of giving linear 100 per cent modulation can be chosen. It is in fact only necessary to restrict the operation to the straight portion of any of the curves, choosing a modulating voltage such that the total swing (total voltage from positive peak to negative peak) will confine the plate current variations to a straight part of the curve. The carrier grid bias can be selected so that the plate current and output will just be reduced to zero when the modulating voltage reaches its negative peak. For example, the characteristic in Fig. 9 is obviously straight from the zero point, which occurs at a grid bias of −95 volts, to the 20-ma. point, where the grid bias is −60 volts. The total bias change and hence the total swing of the modulating voltage, is then 95–60 = 35 volts. The peak value of the modulating voltage is half the total swing, or 17.5 volts. On the negative swing of the modulating voltage the instantaneous grid bias must just reach 95 volts, hence the carrier grid bias will be equal to the maximum instantaneous grid bias minus the peak negative swing of the modulating voltage, or 95−17.5 = 77.5 volts. It is not necessary to utilize *all* of the straight portion of the characteristic to realize linear 100 per cent modulation. For instance, if the modulating voltage has a peak value of 10 volts, the carrier bias would be 95 − 10 = 85 volts and the amplifier output still would be modulated 100 per cent. However, the carrier power output would be smaller in the latter case, since the plate current would be 6 milliamperes as against 10 for the first example, the plate voltage remaining the same. The plate efficiency also would be smaller, since the new carrier operating point is farther down on the grid-bias–plate current curve.

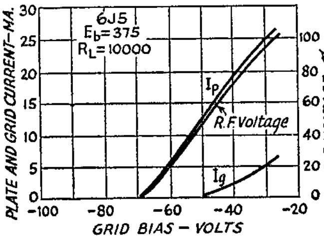

Fig. 11

The upper ends of the characteristics in Figs. 9 and 10 show curvature because the excitation voltage is large enough to "saturate" the amplifier — that is, maximum instantaneous grid voltage and minimum instantaneous plate current are near equality — before the bias is reduced to cut-off. When this is the case the efficiency is high and changes rather slowly with changes in either excitation voltage or bias. As a result, the plate current and power output also change slowly and the curve is no longer linear. The object in adjusting a grid-bias modulated amplifier is to attain maximum efficiency at the modulation peak without operating in the curved region of the characteristic. When this is accomplished the carrier efficiency will have its highest possible value, resulting in the greatest possible carrier power output from the tube or tubes used, consistent with linear 100 per cent modulation. Since the maximum efficiency is in the vicinity of 70 per cent, the carrier efficiency (which is half the maximum efficiency) will be approximately 35 per cent when optimum operating conditions are attained. The permissible power input to the tube can be calculated on this basis (power dissipated by the tube equals

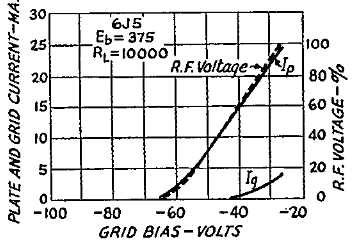

Fig. 12

100 — 35 = 65 per cent of the d.c. plate power input, carrier conditions) and a set of operating conditions worked out so that this carrier input can be used. The 6J5 used in the experiment has a rated plate dissipation of 2.5 watts so that the permissible carrier input is 2.5/0.65 = 3.85 watts.

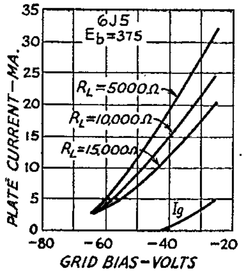

Fig. 13

At the plate voltage used in the measurements described, 375 volts, the permissible carrier plate current is therefore 3.85/375 = 10 milliamperes, approximately. The 10-milliampere point on the curve of Fig. 9 shows that the fixed (carrier) grid bias should be —77.5 volts and the peak modulating voltage 95 — 77.5 = 17.5 volts, the same operating conditions selected before. In Fig. 10 the 10-milliampere point on the curve occurs at a bias of 64 volts and the plate current and output are cut off at 82 volts. The peak modulating voltage required for 100 per cent modulation therefore is 82 — 64 = 18 volts. The modulation peak will occur at 64 — 18 = 46 volts, which is still on the straight portion of the curve. The corresponding operating conditions for the curves of Figs. 11 and 12 can be worked out similarly. It will be observed that in no case does the positive peak of the modulating voltage carry the minimum instantaneous grid bias into the curved region of the characteristic. This indicates that optimum conditions will not be secured with this particular set of curves since the efficiency at the modulation peak will not be as high as is permissible. In Fig. 9, for example, the curvature of the characteristic is negligible up to a bias of about —45 volts, so that it is at approximately this point that the efficiency begins to "level off" at its maximum permissible value of about 70 per cent. If the bias can be swung to —45 volts by the modulating signal the total swing required for 100 per cent modulation will be 95 — 45 = 50 volts and the carrier bias therefore should be set at —70 volts. This will give optimum carrier efficiency, but the plate current is 14 ma. and d.c. plate power input will be in excess of the tube ratings.

Since in every case the efficiency is too low at the modulation peak when the power input is limited to the value set by the tube ratings, a new set of operating conditions must be found which will result in higher peak efficiency. Higher efficiency can be secured by raising the value of load resistance. Take a new set of data with a 15,000-ohm load substituted for the 10,000-ohm load used in the previous measurements, plot the data, and compare the curves to those secured with the 10,000-ohm load. Work out the operating conditions on the basis of the permissible power input as described above. The set which results in operating slightly into the curved region of the characteristic at the modulation peak will be optimum.

Study of the curves of Figs. 9 to 12 will show that the characteristic becomes more linear in the low plate-current region when the grid bias is large and the excitation voltage (as indicated by the value of grid current at cut-off bias) also is large. For this reason it is advisable to operate a grid-bias modulated amplifier in such a way that the minimum instantaneous grid bias is higher than the static cut-off value; that is, the operating angle should be less than 180 degrees at the modulation peak.

EXPERIMENT 34

Operation of Reactance Modulator

Apparatus: The circuit arrangement for this experiment is shown in Fig. 14. The equipment required includes the power supply, bias supply, oscillator, tube board, test instrument, and a calibrated receiver. The reactance tube is a 6J7. The oscillator should be self-controlled, using the self-resonant grid coil. Coil *L* is the movable coil from the circuit board and is substituted for the regular plug-in oscillator plate coil, which should be removed from its socket. The oscillator and the 6J7 screen should be operated at approximately 100 volts; this voltage preferably should be taken from the regulated tap on the power supply, substituting a VR-105-30 for the VR-150-30 normally used. The 6J7 plate voltage, which should be 250 volts approximately, is applied to the tube through a 2.5-millihenry r.f. choke.

C_1 is a midget variable condenser of about 50-$\mu\mu$fd. maximum capacity; the small condenser on the circuit board may be used. The bias for the 6J7 is applied to the grid in series with a 2.5-mh. choke which provides a d.c. path to the grid. The various by-pass condensers, C_2 to C_6, inclusive, may be small mica or non-inductive paper units of 0.001-μfd. capacity or larger; the values are not critical. C_2 and C_3 are blocking condensers to prevent short-circuiting the plate and bias voltages through *L*; the other condensers confine the r.f. currents to the proper paths.

In setting up the circuit keep the r.f. leads short, and separate the plate and grid wiring of the 6J7 as much as possible.

Procedure: In this experiment the effect of circuit constants and operating conditions on the sensitivity and linearity of a reactance modulator are investigated. The frequency change is measured by means of a calibrated receiver. Although the exact frequency need not be known precisely there should be enough band-spread in the receiver to give a fairly open calibration curve, since the experiment can be performed more satisfactory if a frequency difference of the order of one kilocycle can be measured or estimated with fair accuracy. If a few points of known frequency can be spotted on the receiver dial it will suffice to draw a smooth curve through them and assume that the calibration is correct; this will give satisfactory *relative* readings, which is all that is needed for the experiment.

As a preliminary step, disconnect lead "A" from the coil and take the grid voltage–plate current characteristic of the 6J7 (Exp. 25). This is used for comparing the static plate current, at a given value of negative grid bias, to the operating plate current under different conditions of operation. Allow the receiver and oscillator to warm up thoroughly so that frequency drift will not affect the measurements. Set the receiver (with the beat oscillator on) to some value of frequency selected as a reference, such as 3600 kc. Reconnect lead "A", set C_1 at maximum capacity, use a 50,000-ohm 1-watt resistor at *R*, and set the bias on the 6J7 to some high value (30 volts or more) which will insure that its plate current is cut off. Using 25 turns in the coil *L*, set the oscillator plate tuning condenser to bring the oscillator frequency to zero beat with the receiver. Under these conditions the reactance tube is not functioning, since its plate current is

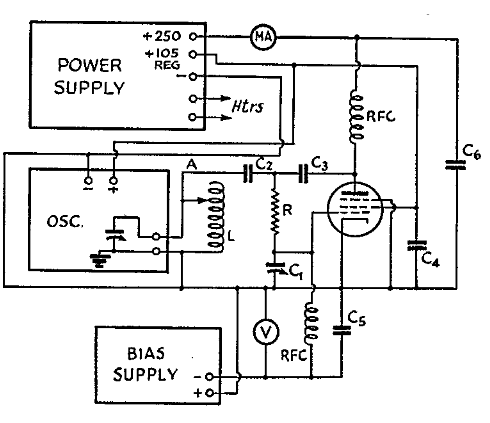

Fig. 14

zero, but the tube and circuit capacities are shunted across the oscillator tuned circuit and hence play their normal part in determining the frequency of oscillation.

Now set the grid bias to zero and measure the new frequency. Increase the bias to one volt and again measure the frequency; continue in this fashion at 1-volt intervals until the frequency has returned to its original value. When this run is complete, set C_1 at half capacity and repeat. Finally, set C_1 at minimum capacity and take a similar set of readings. Plot the data in the form of curves showing frequency as a function of grid-bias voltage applied to the reactance tube.

Fig. 15 shows the result of such a procedure, curve A being for maximum capacity (50 μμfd. in this case). B for half capacity and C for minimum capacity. The reactance of C_1 increases with decreasing capacity, but since the reactance in any case is small compared to the resistance of R the current in the circuit formed by R and C_1 changes relatively little. Hence the voltage across C_1 is approximately proportional to the reactance of the condenser, and increases as the capacity is made smaller. Since this voltage is applied to the grid of the reactance tube the r.f. component of plate current also increases when C_1 is made smaller, for a given value of grid bias. As a result, the shift in frequency also is larger.

All three curves have a straight portion in the middle, with curvature at both ends. In using the tube for frequency modulation only the straight portion would be used. In the case of curve A, the straight portion extends from approximately —3 volts to —6 volts. The operating point would be set in the middle of this region — that is, the fixed grid bias would be set at —4.5 volts — and linear modulation would be secured with a peak audio grid voltage of 1.5 volts. The total frequency swing is then 22 kilocycles, from a frequency of 3628 kc. at —3 volts bias to 3606 kc. at —6 volts bias. The frequency deviation, which is half the total swing, is thus 11 kilocycles. In curve B the approximately straight portion lies between the limits of —3 and —7 volts, so that the operating bias would be —5 volts and the peak audio voltage would be 2 volts. The deviation in this case is 14.5 kc. Curve C has a much longer straight portion — from —3 to —12 volts, giving a deviation of 24 kc. at the maximum permissible audio modulating voltage.

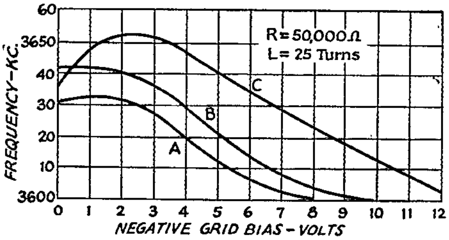

Fig. 15

In some respects the reactance tube operates in much the same way as a grid-bias modulated amplifier; that is, the amplification is a function of the grid bias, the amplitude of the r.f voltage applied to the grid being fixed. The curvature of the characteristics below —3 volts in Fig. 15 is partly caused by saturation effects similar to those observed with grid-bias modulated amplifiers when the grid bias is made too small (Exp. 33) and partly because the resistance of the grid circuit decreases rapidly when the grid is driven into the positive region. In the case of the reactance modulator this grid resistance is in parallel with C_1. When the grid resistance approaches the reactance of C_1 in order of magnitude, the phase angle between voltage and current in the circuit formed by C_1 and the grid resistance decreases. As a result. the r.f. component of plate current does not lag exactly 90 degrees behind the voltage across the tank circuit, and consequently the effectiveness of the tube as shunt inductance across the tank is reduced. If the grid resistance becomes comparatively low, the combination of the two effects can result in a reversal of the normal trend of frequency with changing grid bias. This is evident in the left-hand portion of curve C.

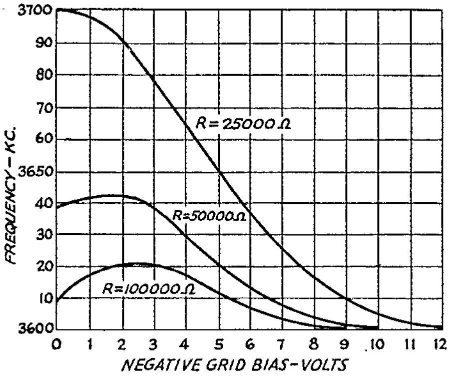

Fig. 16

The curvature at the high-bias ends of the characteristics is the "tailing off" effect usually encountered with variation in bias near the plate-current cut-off point, and is attributable to the change in tube amplification factor in this region.

For the second part of the experiment, set C_1 at about half capacity and take readings similar to the above, but with 100,000 ohms substituted for the 50,000-ohm resistor first used at R. When this run is finished. substitute a 25,000-ohm resistor at R and repeat. Plot the data in the same form as before. Fig. 16 shows the results of a typical run of this type. For a fixed value of capacity at C_1, the current through RC_1, and hence the voltage across C_1, is dependent upon the value of resistance used at R, smaller values giving larger current and vice versa. This is clearly shown by the experimental curves, since the frequency shift, which is proportional to the r.f. voltage across C_1, increases with decreasing resistance at any given value of grid bias. In other respects the curves have the same general nature.

The effect of the L/C ratio of the tank circuit on frequency deviation can be observed by repeating the first set of measurements, using 15 turns in L instead of 25. The sensitivity of the modulator can be expected to decrease; that is, the same change in bias voltage should give a smaller change in frequency, other conditions remaining the same. For a given value of r.f. voltage at the grid of the reactance tube the r.f. component of plate current of the tube will be the same (provided the tank circuit impedance has not changed greatly) regardless of the L/C ratio. However, the smaller the L/C ratio the greater the tank current. When the fixed reactance tube r.f. plate current is added to a small tank current its effect on the resultant phase angle, and hence on the frequency, is greater than when it is added to a large tank current. Hence the frequency swing for a given change in modulator bias is less when the L/C ratio is small.

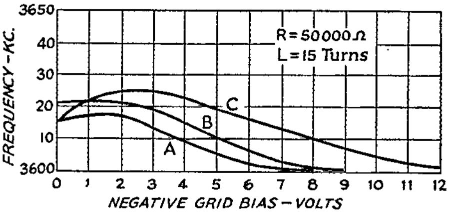

Fig. 17

The experimental measurements will show this. Fig. 17 is a typical set of curves. which may be compared directly with those of Fig. 15. It can be seen that the frequency deviation has been halved, approximately, by using 15 turns in the tank coil in place of the 25 used in securing the data plotted in Fig. 15.

(Continued on page 116)

A Course In Radio Fundamentals

(*Continued from page 61*)

In each set of measurements it is useful to measure the d.c. plate current of the 6J7 and compare it to the static plate current at the same value of grid bias. The operating plate current in general will be larger. The increase over the static plate current gives an indication of the amplitude of the r.f. voltage applied to the grid of the reactance tube.

ANSWERS TO QUESTIONS IN INSTALLMENT 5

If no answer is given, it is to be found in the appropriate *Handbook* section or in the description of the experiment or experiments accompanying that Assignment.

Assignment 17:

Q. 16 — 250 μμfd. or larger.
Q. 17 — 60 μμfd. or larger.
Q. 18 — In plate circuit, 38 μμfd. and 13.7 μh; in grid circuit, 57 μμfd. and 9.1 μh.

Assignment 18:

Q. 6 — Operating bias, —133 volts; r.f. grid voltage, 179 volts r.m.s.
Q 7 — Operating bias, —260 volts; r.f. grid voltage, 280 volts peak.
Q. 8 — 21 ma.
Q. 9 — 160 μμfd. for B; 80 μμfd. per section for E.
Q. 10 — 7 μh.

Assignment 19:

Q. 17 — ¼ wavelength (2.2 feet) or integral multiple thereof. Frequency with tube connected would be lower.

Note. — Through a typographical error the first part of the answer to Q. 12, Assignment 12, October *QST*, was shown as 01.75 watts. It should be 0.175 watts.

The Navy Trains Radio Technicians

(*Continued from page 18*)

Here is the program for a typical day:

0600 Reveille. Bunks are made and rooms cleaned by 0620.
0630 All hands assemble for 30 minutes of setting-up exercises and drill.
0710 Breakfast.
0800 Classes and laboratory; two 2-hour periods.
1200 Lunch.
1300 Classes and laboratory; two 2-hour periods.
1700 Evening meal.
1830–2000 Athletic program and study period.

Course Stresses Math and Theory

As the training gets under way he finds that it is divided into four main headings: D.c. theory, and mathematics, a.c. theory and radio. The first two months are devoted to intensive math drills, physics, direct current and mechanical drawing.

And if he thinks that he already knows enough about these subjects to get by, he is in for some stiff disillusionment. Regardless of how good his earlier training may have been, he'll find there's plenty he didn't know. There was one graduate