RADIOTRONICS

AMALGAMATED WIRELESS VALVE CO. PTY. LTD.

BOX No. 2516 BB G.P.O., SYDNEY

TECHNICAL BULLETIN No. 77 **30th JUNE, 1937**

In this issue:—

FOR THE RADIO ENGINEER

PUSH-PULL 2A3 FIDELITY AMPLIFIER

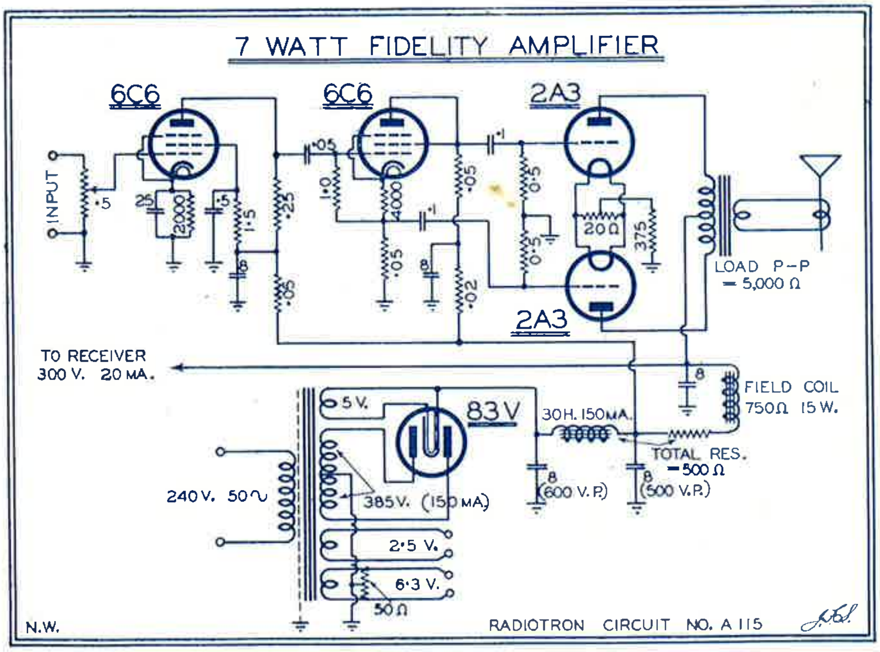

Fig. 1

It is generally agreed that for the highest fidelity it is desirable to use triode power valves. Radiotron circuit D41 incorporates a single Radiotron 2A3, giving an output of 3.5 watts with no appreciable distortion, but there are certain applications in large receivers where a greater output is desirable. Two Radiotron 2A3's in push-pull appear at first sight to be very attractive and to form a readily applied combination, but it has generally been found that an audio transformer is necessary in order to give sufficient swing to excite the grids of the 2A3's. As the result of development work completed in the laboratory of Amalgamated Wireless Valve Co. Pty. Ltd. it is possible to use a resistance coupled arrangement throughout which gives an excellent frequency response with a minimum of distortion. Tests made over the complete amplifier operating from an input of 0.24 volt

PUSH-PULL 2A3 FIDELITY AMPLIFIER—Continued.

into a loud speaker load gave a power output of 7 watts with a total harmonic distortion not rising above 2.5% under all conditions. A considerable part of this distortion is second harmonic; the higher audio harmonics are almost completely absent and the circuit may be regarded as giving, under all conditions, less distortion than is audible to the human ear. Due to the use of Radiotron 6C6 as a high gain resistance coupled pentode together with a similar valve operating as a triode phase splitter, it has been found possible to operate over a very wide range of audio frequencies extending from below 30~ to over 10,000~.

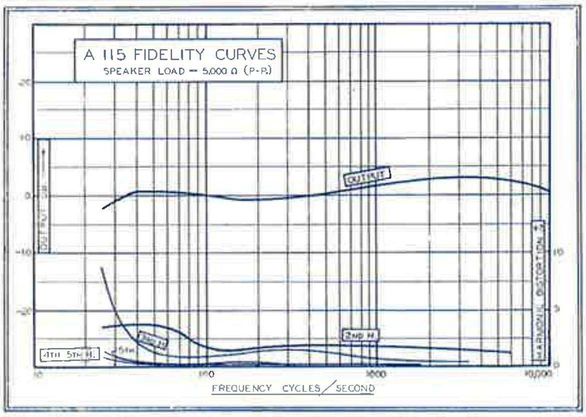

Fig. 2

When experiments first commenced, Class AB1 operating conditions were investigated, but it was found necessary with this arrangement to feed the loud speaker field coil in shunt with the receiver and to adopt a very good regulation power supply and filter. These difficulties led to the adoption of a pure Class A condition in which the loud speaker field can be used for filtering purposes and a very economical design is therefore possible. Another advantage of Class A operation is that the audio harmonics are extremely low and barely measurable. Further advantages are that self-bias can be used without the necessity for a cathode by-pass capacity, as is necessary in self-bias Class AB1, and that the power stage is much more easily excited since it needs a smaller voltage from grid to grid.

It is hoped that at some later date it may be possible to describe a push-pull 2A3 amplifier giving 15 watts output on fixed bias and incorporating a special method of driving the output stages without exceeding their maximum grid resistance of 50,000 ohms for fixed bias. In the present amplifier only 250 volts are required on the plates and 45 volts for grid bias, which, together with the drop in the speaker transformer, only amounts to slightly over 300 volts supply voltage. Radiotron 83V has been adopted as a rectifier valve since it enables a standard transformer 385-385 volts 150mA to be used together with standard electrolytic condensers, while still permitting the loud speaker field to be connected in the plate circuit. Since the amplifier is capable of responding to very low audio frequencies, it is essential that the power supply should be adequately filtered and a two stage filter is used in which the loud speaker field forms one of the chokes and a separate power choke the other. Additional smoothing is obtained for the earlier stages by the use of dropping resistors and separate 8μF condensers.

In order to obtain sufficient voltage for the grids of the 2A3's it was decided to use a phase splitting valve with equal resistors in the plate and cathode circuits. The input to this stage is between grid and earth and the stage gain is approximately 1.8 times from input to total output grid to grid. The 2A3 valves require a peak voltage from grid to grid of 90 volts for full output and in order to obtain this swing without any appreciable distortion, the voltage supply of both earlier stages was derived from the first stage of the filter, giving over 400 volts. The amplifier as a whole thus uses standard components without involving any heavy expense for high fidelity audio transformers. The sensitivity is ample for it to operate from any radio receiver or from any pick-up. The frequency response is wider than that given by any broadcast station or gramophone record. The harmonic distortion is lower than that given by a broadcast station or sound on film recording. The power output is ample for home use with a loud speaker of ordinary sensitivity and it is generally agreed that a higher output is not normally required. It

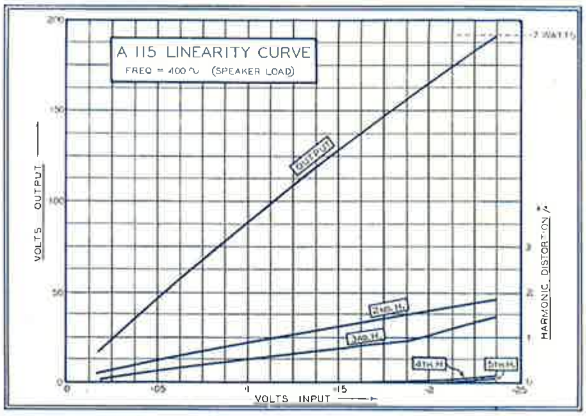

Fig. 3

is hoped that at some future date a fidelity superhet. receiver circuit will be described incorporating this amplifier, and the complete assembly should be capable of giving a response coming well within the highest standards of fidelity in all respects. It is emphasised that variations from the circuit diagram may involve overloading and distortion together with a reduction of power output and constructors are urged to adhere exactly to the values of resistances, condensers and voltages given in the circuit diagram. Owing to the use of Class A operation and self-bias there is no necessity for the output valves to be specially matched. Measurements of hum level showed that the hum was more than 50 db. below maximum output, the range being − 13 to + 38.5 db. The circuit diagram is shown in Fig. 1, while the output is plotted against frequency and input voltage in Figs. 2 and 3 respectively. Both Figs. 2 and 3 are the results obtained on a typical 12in. loudspeaker load, and this was done purposely so as to demonstrate the results under practical operating conditions. The distortion and frequency response on a resistive load are distinctly superior to those shown, which are limited by the characteristics of the loud-speaker.

AUTOMATIC VOLUME CONTROL

General Principles:

A perfect automatic gain control would provide equal *mean* input to the manual volume control on all signals under all conditions of fading. As the receiver must have maximum sensitivity in the absence of signals, the control must *reduce* the gain for strong signals, the reduction varying with signal input. If the *audio* signal were reduced to a common level, its entertainment value would be lost, for besides losing all expression, the lower levels would be marred by the increase in background noise. It is necessary, therefore, to control the gain by the mean *carrier* level.

The obvious method of control is the application of additional bias to the grids of the radio frequency, converter and intermediate frequency stages of the receiver. In such cases, though the control may be good, it can never be perfect, i.e., the mean carrier levels at the detector cannot be equal for all levels of signal input, because the controlling voltage itself would not vary. For more effective A.V.C., control bias may be applied to the audio stages of a receiver, to make the overall gain inversely proportional to the signal input voltage at the aerial terminal. Audio A.V.C., however, is not always as desirable as its improvement in control warrants. Within certain limits, the R.F. and I.F. valves may be operated on the curved portions of their characteristics without the introduction of excessive distortion. Such is not the case with audio A.V.C., which may introduce serious harmonic distortion if not applied with care.

Valves for A.V.C.

The valves employed as controlled stages must have characteristics such that the gain falls steadily as the grid bias is made more negative. Since the gain of an R.F. or I.F. stage is nearly proportional to the mutual conductance of the valve, it is necessary to use valves having "super-control characteristics" in which the mutual conductance gradually decreases as the bias is made more negative. These are also known as "variable-mu" valves, since the amplification factor as well as the mutual conductance varies when the bias is changed. The "super-control" characteristic is obtained by winding the control grid with a non-uniform pitch so that the gaps between some of the turns are greater than others. The consequence is that at high negative grid voltages the plate current is completely blocked between the closer turns, while still flowing through the wider gaps. A "super-control" characteristic provides a gradual tailing-off so that a sharp cut-off of the plate current is avoided. For a more complete discussion on super-control characteristics, the reader is referred to Page 16 of the Radiotron Receiving Manual RC13.

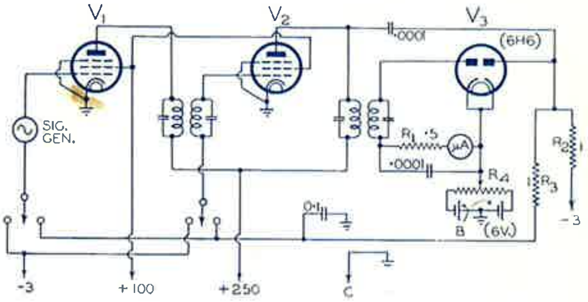

Fig. 4

For the most effective control, the fall in plate current and mutual conductance should be rather rapid, and the actual cut-off grid voltage should be little more than that of the sharp cut-off equivalent. Valves having such characteristics are, however, prone to distort the modulation envelope rather badly, as at large signal inputs the peaks of modulation on the positive side of the carrier may be amplified much more than the troughs. It is better, therefore, to sacrifice some control for

AUTOMATIC VOLUME CONTROL—Continued.

the sake of fidelity, and a good example is found in the 6D6, which has a cut-off at about —50 volts bias with 100 volts applied to its screen grid.

To provide a negative bias voltage for control purposes, some form of rectifier is required. Diode plates have been incorporated together with other electrodes in types 55, 75, 85, 2A6, 6B7S, 2B7, 6B8, 6Q7, 6R7, 1B5 and 1K6. The 6B7S has a super control pentode unit included with its two diodes, and may be used to advantage as a final I.F. stage and detector. It leaves the choice of audio stages in the designer's hands, and has made negative feedback a practicability with resistance coupled stages. (See Radiotronics 74.)

Experimental Results:

To determine experimentally what one may expect from controlled stages, two intermediate frequency stages were set up as in Fig. 4. The amplifier was tuned to 465 K.C., and the I.F. transformers were of standard manufacture with mutually coupled iron-dust cored coils. The A.V.C. diode of the 6H6 was fed from the plate of V_2 through a 100 $\mu\mu$F condenser, and the rectified current set up a voltage across R_2, which was applied to the grids through the resistance R_3. The detector diode was loaded with a resistor R_1, and a variable negative bias was provided for the A.V.C. diode by the battery B and a potential divider R_4. The output was read off as a current through R_1, and was converted to a decibel law by the simple computation, *20 log I*. The input from the signal generator was varied in steps of 10 dB ($\sqrt{10}$ voltage ratio) over a range 10 to 10^6 microvolts.

The curves in Fig. 5 show the action of the A.V.C. where no standing bias is present between diode plate and cathode in the 6H6. **Curve A** shows the output for variation of voltage input when A.V.C. is applied to V_2 only. A difference of 18 db is noticed through the working range of 10^3 to 10^5 microvolts. It will be seen that above an input of about 10^4 microvolts the output curve tends to bend upwards, this effect indicating distortion of the modulation envelope.

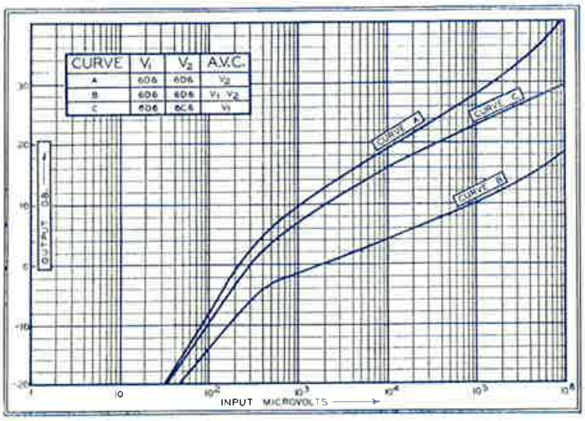

Fig. 5

For **Curve B**, both V_1 and V_2 were controlled, and the effect shows marked improvement, there being only 11 db increase in output for 10^3 to 10^5 microvolts. As in Curve A, there is still a slight tendency for the curve to bend upwards, but the effect is much less pronounced. This is on account of the two controlled stages giving more effective A.V.C. action and resulting in a higher input voltage being required to produce the same output.

In the case of **Curve C**, only V_1 was controlled by the A.V.C., and it would appear at first sight that the result should be identical with Curve A, but it is evident that the two curves are considerably different. Since V_2 was operated at fixed bias, there was less distortion in the plate circuit, which eliminated any tendency for the curve to bend upwards at high input levels, and provided a considerably improved control characteristic as compared with Curve A. There is also another effect which assists in giving a good control characteristic, since in the case of Curve C there is virtually amplification of the controlling voltage due to the stage V_2 between the controlled stage and the rectifier V_3. To some extent this acts in a similar way to amplified A.V.C., and the control is increased with an increase in the amplification of V_2.

Delayed A.V.C.:

As A.V.C. results in a gain reduction, simple A.V.C. systems tend to reduce the level of even the weakest signals. It is wise, therefore, to devise some limiting means for providing a threshold of signal level beyond which control commences. Such a system is said to provide *delayed* A.V.C., and its action is to delay the operation of the control until the received signal exceeds a predetermined level. In its simplest form it is merely a negative bias applied between plate and cathode of the A.V.C. diode. Current only flows when the voltage at the diode plate exceeds the bias voltage.

Delayed A.V.C. also tends to make the control more effective after the delay voltage has been exceeded. The fall in gain is most rapid where the applied bias is small, and when the control begins at a point where the signal is large, the sudden reduction in gain causes a sharp knee with a fairly level portion in the curve of output against input.

In the set up of fig. 4, the delay bias was varied from 0 to 6V in two steps of 3V. Control was

AUTOMATIC VOLUME CONTROL—Continued.

applied to both stages, each being Radiotron 6D6. In fig. 6, Curve A was taken without delay, B with 3 volts delay and C with 6 volts. Each step shows an improvement in control on the previous delay voltage.

The actual input voltage at which the knee occurs depends jointly upon the delay voltage and the gain of the receiver between the aerial terminal and detector. The higher the sensitivity, the smaller will be the required input voltage (at the aerial terminal) to operate the A.V.C. A simple method for fixing the delay voltage is to allow the final audio valve to become fully loaded with a fully modulated input before the A.V.C. diode current flows. Where the sensitivity of the receiver is good, the delay voltage thus determined may be increased, and the receiver will be operated normally with its manual volume control at some point below its maximum setting. In such a case, the shunt loading on the detector diode load is reduced, and less distortion is likely to occur.

The most generally adopted delay voltage is the bias on the cathode of the multiple valve, which includes the A.V.C. diode. When the valve is used as the first audio stage, this bias will rarely exceed 2 volts. A 6B7S I.F. stage requires 3 volts minimum grid bias, and provides more delay, with a more effective overall control characteristic.

Practical Application:

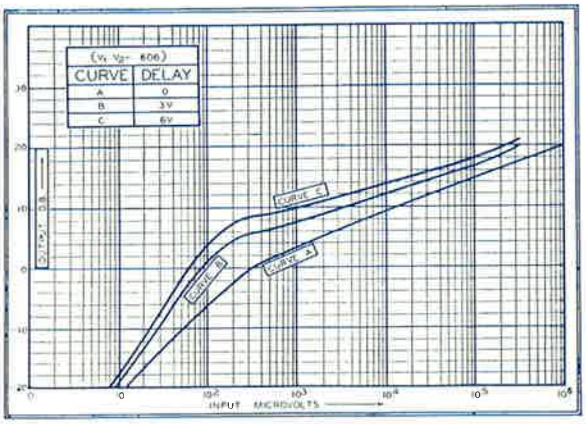

Fig. 6

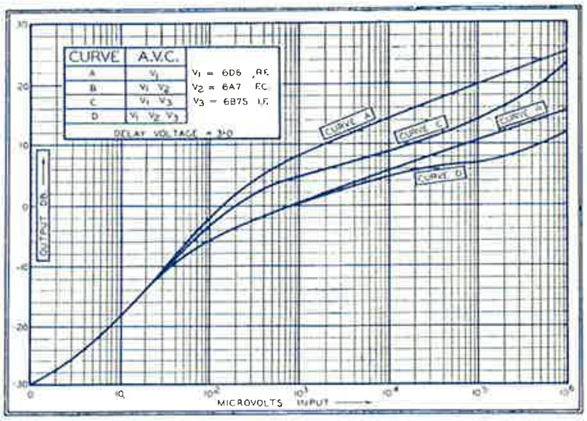

Fig. 7

To study the effects of A.V.C. in a practical receiver, an R.F. stage, using a 6D6 valve, was added to Radiotron Circuit D42. The four combinations—6D6 only; 6D6 and 6A7; 6D6 and 6B7S; 6D6, 6A7 and 6B7S, were tried in sequence, and their output/input curves were plotted in fig. 7. Curve A shows control applied to the R.F. stage only, and the effectiveness of the control is seen to be not very great. Curve B shows control applied to the R.F. and Converter stages, Curve C to R.F. and I.F. stages, and Curve D to all three stages. Curves A and B do not apply A.V.C. to the I.F. stage, and they do not exhibit any tendency to bend upwards, while Curves C and D, which both apply control to the I.F. stage, do show this effect. However, it is clear that Curves C and D provide a sharper knee in the curve, and therefore, possess an important advantage. The difference between Curves B and D is not so pronounced as that between Curves A and C, and this is at least partly due to the amplification effect between the controlled stage and the rectifier.

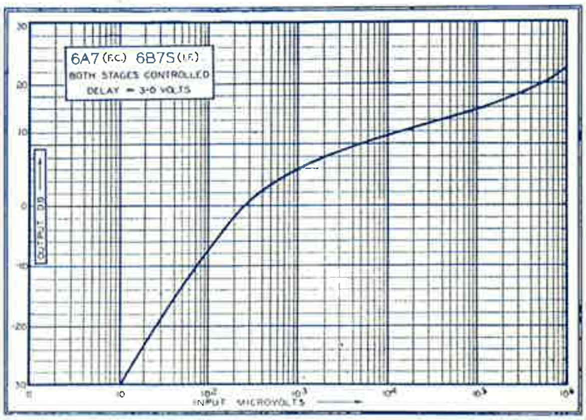

Fig. 8

For fig. 8 the grid clip from the aerial section of the tuner was connected to the grid of the 6A7.

AUTOMATIC VOLUME CONTROL—Continued.

The reduction of sensitivity has shifted the knee of the curve, and approximately ten times as much input is required to operate the A.V.C.

Selectivity and A.V.C.:

A diode rectifier is essentially a power operated device, and must be provided with power and not voltage only. The input resistance of a diode rectifier having a paralleled condenser and resistive load may be taken as approximately half the D.C. resistive load. When the diode is shunt fed, as in fig. 9, the input resistance of the diode itself has also the load resistance and filter resistance in shunt. The total resistance shunted across the primary of the last I.F. transformer is thus

$$R_S = 1/(3/R_L + 1/R_F + 1/R_P).$$

Where R_S = *total shunt resistance.*
R_L = *A.V.C. diode load resistance.*
R_F = *filter resistance.*
R_P = *plate resistance of last I.F. valve.*
while current is flowing.

In the absence of current the input resistance of the diode is almost infinite, and

$$R_S = 1/(1/R_L + 1/R_F + 1/R_P).$$

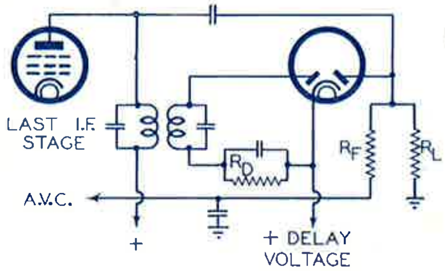

Fig. 9

It is obvious that the damping effect of the shunt load is more pronounced when the dynamic resistance of the coil is high. Consequently, in order to reduce the damping effect it is beneficial to reduce the dynamic resistance while still keeping the Q factor of the coil high. This can be done by reducing the resistance of the coil, together with a decrease in the L/C ratio. In other words, the damping is reduced when a low L/C ratio coil of high Q factor is employed. Moreover, the change of loading where the A.V.C. diode commences to pass current is less likely to upset the selectivity of the circuit.

In fig. 10 another arrangement for feeding the voltage to the A.V.C. diode is shown. It is fed from the detector diode instead of from the I.F. plate. The voltage level at the detector is necessarily lower than that at the primary of the last I.F. transformer. The A.V.C. is thus less effective than when the control diode is coupled to the I.F. plate. By reducing the coupling between the coils of the I.F. transformer, the selectivity of fig. 10 can be made better than that with fig. 9, but the gain is then reduced, and the A.V.C. characteristic with it.

All A.V.C. systems have the effect of making the selectivity of a receiver *appear* less than it really is. Consider a signal of constant frequency and depth of modulation. As a receiver is tuned through resonance with the signal, its A.V.C. circuit reduces the gain of the receiver as the input to the detector increases, and the signal output does not rise to the sharp peak attained with receivers having no A.V.C. It is important to remember, however, that interfering signals are reduced in level in the same proportion as the signal itself.

When the method shown in fig. 9 is used, the A.V.C. operates further from resonance than in the case of fig. 10. The result is that, owing to the greater selectivity of the secondary, the signal output does not begin to rise until the sensitivity has been reduced, and the peak of output is more pronounced than with secondary feed. The *apparent* selectivity is thereby enhanced, while the *actual* selectivity may be poorer than that measured by the conventional method of plotting signal inputs for frequencies off resonance required to give standard (or constant) output. At frequencies where the required input is more than 10^3 times up, the difference in selectivity between the primary and secondary of the last I.F. transformer may cause sufficient difference in voltage to operate the A.V.C., even though the output at the detector may be well below the knee of the operating curve. A more useful measure of selectivity is the measurement of the difference in output of two signals equal in carrier level and different in frequency, when the receiver is tuned to one of them.

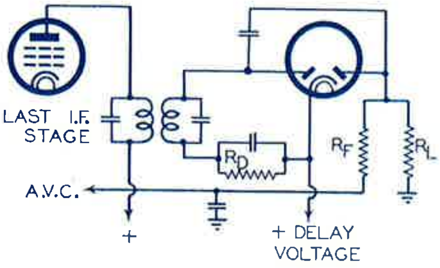

Fig. 10

Corrections to Radiotronics 76.

You are asked to make the following corrections in your copy of Radiotronics 76:—

Page 38, Equation 1: Add a small bracket immediately before the — sign, so as to close the expression.

Page 39, Equation 7: Change the — sign in the denominator to ×.

Page 40, Summary (d): Change to read $R_t = 1/2\pi f_h C_s$.

Page 42, Bibliography (3): Should read W. T. Cocking "Resistance Coupled Amplifiers."

Page 42, 913 Oscillograph Circuit: Change 885 cathode bypass condenser to read 25μF.

EXPERIMENTERS SECTION

SERIES MODULATION

Experimenters generally have avoided the use of series-modulation, firstly, because of the high voltages necessary, and secondly, because such a system necessitates the use of a low-efficiency class A modulator. Despite these drawbacks, series-modulation has advantages, particularly when used in low power amateur transmitters. The most attractive feature lies in the fact that good quality 90-95% modulation may be obtained without the use of a costly modulation transformer or choke.

While the voltages are necessarily high, it must be remembered that the current requirements are low in proportion. Hence, it is usually quite practicable to adapt standard full wave transformers to half wave operation, so as to obtain twice the normal voltage at half the normal current. Regulation is not important, as the current drawn by a series-modulated transmitter is practically constant, irrespective of modulation depth.

One less obvious, but nevertheless, important advantage of the system is that over-modulation of the carrier does not cause the radiation of spurious sidebands many kilocycles removed from the carrier. This is because the plate voltage on the modulated amplifier can never be forced negative, as may occur in other systems of plate modulation. Although generally considered critical in operation, a series modulated transmitter need cause no difficulty, provided a little care is taken in the design.

When the plate voltage of a class C amplifier is varied, the plate current obeys an almost linear law, so that the stage may be regarded practically as a pure resistance. In series modulation, a modulator valve is placed between the class C stage and the negative return to the H.T. power supply. The class C stage then represents a resistive load on the modulator and can be treated as such for purposes of design.

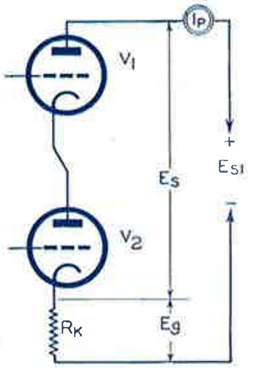

Fig. 11

Fig. 11 shows a typical case, in which V_1 is the modulated amplifier and V_2 the modulator. Fig. 12 is a typical curve, in which modulator plate current is plotted against plate voltage for different values of grid bias. If V_1 is to be fully modulated then its plate current must vary between zero and twice the mean plate current (I_p). Since V_2 must operate without grid current, peak plate current ($2I_p$) must flow when the grid bias (E_g) is zero. On the zero bias curve for the modulator mark the point "A" where the current is equal to $2I_p$. Note also the minimum voltage drop across V_1, shown as E_d.

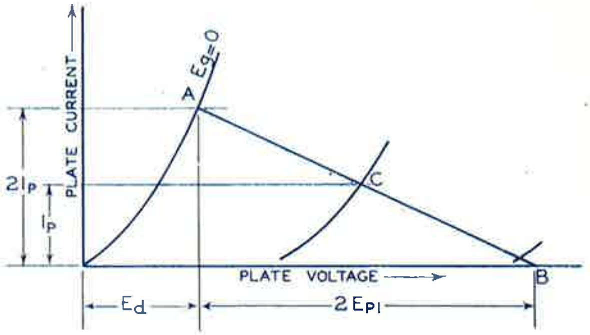

Fig. 12

Since the point of peak current must also be the point where the voltage on the plate of V_1 is twice its normal value (E_{p_1}), it follows then that the voltage E_s must be twice the rated voltage for V_1 plus the voltage E_d.

On the curve plot this point "B" corresponding to $2E_{p_1} + E_d$. Join AB and mark a third point "C" where AB cuts the line of mean plate current I_p. The value of E_g at C will be approximately the operating bias of the modulator.

The modulator bias resistor R_K may now be found by the formula: $R_K = (E_g \times 1100)/I_p$ where I_p is the plate current in milliamps. Due to the slight non-linearity of the curves, I_p does not occur at exactly half-cut-off bias, but this is partly compensated by a slight rise in bias across R_K during modulation. A further compensating factor of 1.1 is introduced in the formula which is sufficiently accurate for all practical purposes. The

EXPERIMENTERS' SECTION

bias voltage E_c developed across R_K is in series with E_s, so that total supply voltage (E_{s1}) will be equal to $E_d + 2E_{p1} + E_c$.

Where the wattage dissipation at the point C exceeds that permissible on V_2, two or more modulator valves may be used in parallel. In this case the mean and peak currents will be equally divided between all the modulator valves, while values of I_p and $2I_p$ on the curves will be those for a single valve. R_K will, of course, be dependent on the total I_p.

Should the supply voltage E_{s1} be more than 2.5 to 3 times the maximum rating of the valve in Class A operation, a valve with a higher voltage rating should be chosen. It should be noted that the peak audio input voltage to the grid of the modulator valves used in series modulation is somewhat higher than under usual conditions, being equal to the D.C. bias voltage. Pentodes are generally not suitable as modulators, since they are very critical in regard to load resistance.

Since the modulated amplifier (V_1) has its filament above earth, both in relation to D.C. and to audio voltages, it is necessary for its supply to be insulated for a D.C. voltage equal to the supply voltage. A separate filament transformer is desirable for this reason, although not essential if due precautions are taken. The capacity between this filament circuit and earth should be just sufficient to bypass Radio Frequencies without attenuating the higher Audio Frequencies. A typical value is .00025 μF. Where the R.F. Amplifier is a pentode (as in the accompanying circuit) the screen is series fed from the plate supply and bypassed for R.F. only.

Fig. 13 shows a typical series modulated stage using an input of 25 watts to the R.F. Amplifier. The Carrier Power output is 13.5 watts.

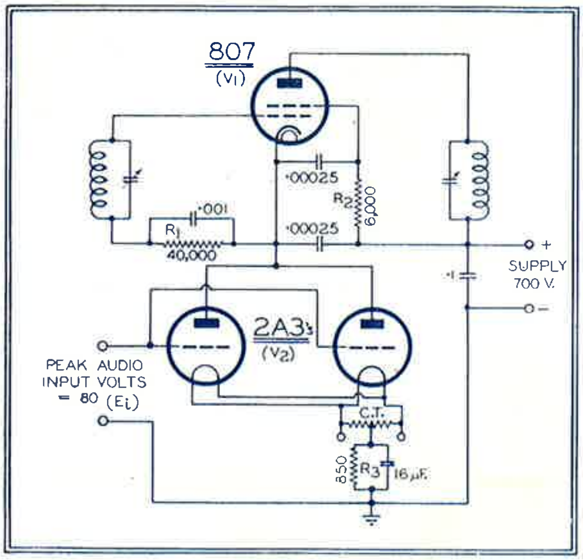

Fig. 13

The accompanying table shows the necessary modifications for use with other popular valve combinations. Where necessary, neutralising is added in the usual manner.

SERIES MODULATION DATA

Final Radiotron.	Modulator Radiotron.	Supply Volts.	Current Drain (mA)	R_1	R_2	R_3	E_i (Peak)	Power Input to Modulated Amplifier (Watts)	Carrier Power Output (Watts)
807	2–2A3	700	89	40,000	6.000	900	80	25	13.5
807	2–50	950	89	50,000	6,000	1,350	130	29	17
10	2A3	635	45	6,500	—	1,700	75	11	5.5
10	50	1000	45	9,000	—	2,750	135	16	8
P.P.10's	2–50	1000	90	4,500	—	1,350	135	32	16
808	2–845	3000	100	7,000	—	2,700	275	125	105

Radiotron 866 (Australian price, 25/- nett), operating as a half-wave rectifier, is recommended for voltages up to 1,000 volts in this table.

Published by The Wireless Press for Amalgamated Wireless Valve Co. Pty. Ltd.