AN ELECTRON TUBE AMPLIFIER FOR AMPLIFYING DIRECT CURRENT

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In various fields in electrical work, particularly in radio work, it is important to have a relay possessing negligible time lag, capable of operating on small impressed currents, of the order of 10 milliamperes. Such a device may be found useful, for example, in recorders for registering telegraphic or radio signals, in apparatus for remote electrical control, in railway signaling work, and for operating an oscillograph from a source of very small current.

The following paper describes a resistance coupled electron tube amplifier designed to amplify a direct or alternating current of 10 to 20 milliamperes to 110 to 200 milliamperes to take the place of a special type of polarized relay at present used for this purpose. The conditions under which the relay operates and which are imposed on the amplifier follow:

CONDITIONS

The current operating the relay is either an alternating current of 10 to 20 milliamperes at a frequency of about 40 cycles or a direct current of the same magnitude in either direction, both of which are applied intermittently from a high impedance source. The input impedance of the relay is about 750 ohms with an allowable increase to 1000 ohms. The impedance of the output circuit is 50 to 100 ohms. When a direct current in a given direction is supplied to the input of the amplifier, an amplified direct current will be produced in the output circuit. When a direct current in the opposite direction is supplied to the input, an amplified direct current in the opposite direction will be produced in the output circuit. The amplifier will amplify alternating currents of either low commercial frequencies or high radio frequencies with very little distortion.

TUBES

The electron tubes selected for the amplifier tests were UV-202 Radiotron 5 watt power tubes, because of their high filament emission and steadiness of operation with a high plate current.

CIRCUITS

Since the electron tube amplifier is essentially a voltage operated device of high impedance, it is not readily adapted for efficient current amplification. For highest efficiency the highest possible voltage should be produced from the input current it is desired to amplify. The type of amplifier circuit that may be used is limited by the fact that the input consists partially of direct current, to a resistance coupled circuit employing the voltage drop across a resistance for the input to each stage, so the maximum voltage available with 10 milliamperes flowing in the input circuit is the drop across a resistance in the input circuit. The resistance being limited to 1000 ohms, the maximum voltage available is 10 volts. This requires more than one stage of amplification for efficient use of the tubes.

CIRCUIT 1,

CIRCUIT 2,

FIG. 1—Amplifier circuits

CIRCUIT DESCRIPTION

Two circuits each having two resistance-coupled stages were set up and adjusted for maximum current amplification. These circuits are shown diagrammatically in Fig. 1.

In both circuits 1 and 2 of Fig. 1:

A and B are the input terminals.

C and D are the output terminals.

E (in dotted lines) represents the impedance of the output circuit. In these tests E was a resistance of 50 ohms.

F , G , and P are respectively the filaments, grids and plates of the tubes.

H = First stage.

K = Second stage. For simplicity only one tube is shown in each stage, although several connected in parallel were used.

B_1 and B_2 = 8 volt batteries of sufficient capacity to supply the filaments connected to each battery. Each tube requires 2.3 amperes.

B_3 = Source of grid voltage of 22 to 110 volts, according to tubes used, capable of carrying about 40 milliamperes in a direction opposite to the voltage of this source.

B_4 = Source of plate voltage, 220 volts, capable of delivering 0.5 amperes.

B_5 = 40 volt battery to supply 200 milliamperes.

B_6 = (circuit 2 only) 12 volt battery to supply 20 milliamperes.

R_1 = Input resistance of 1000 ohms. The sensitivity of the amplifier can be controlled completely by varying this resistance. Increasing the resistance increases the current amplification and reducing the resistance decreases the amplification.

R_2 = Coupling resistance of 10 000 ohms to 55 000 ohms, according to number of tubes used. Both R_1 and R_2 should have a current capacity of 30 milliamperes.

R_3 = Resistance which must be variable by small steps from 150 to 300 ohms, such as a slide wire rheostat. Current carrying capacity 200 milliamperes.

TESTS

With the two circuits shown in Fig. 1 adjusted to give the highest amplification, measurements were made of the output current

for an input voltage of 10 volts positive and negative which corresponds to an input current of 10 milliamperes through the input resistance of 1000 ohms. The current amplification, that is, the ratio of the output to the input current, is obtained by dividing the measured output current by the 10 milliampere input current.

RESULTS

The following table shows the amplification obtained with both circuits, using the tubes as indicated in the first three columns and also gives the values of coupling resistance and grid voltage (R_2 and B_3 respectively of Fig. 1) required for best operation in each case:

TABLE 1
Circuit 1

Total No.	Number of Tubes		R_2 Ohms	B_2 Volts	Output Current with 10 ma input	Current Amplification
	First Stage	Second Stage				
2 ¹	1	1	46 000	100	60	6
3 ¹	1	2	46 000	100	100	10
4	1	3	56 000	88	120	12
5	2	3	14 000	110	130	13
6	2	4	14 000	110	160	16

TABLE 1
Circuit 2

Total No.	Number of Tubes		R_2 ohms	B_2 volts	Output Current with 10 ma input	Current Amplification
	First Stage	Second Stage				
3 ¹	1	2	12 000	45	70	7
4 ¹	2	2	8 000	35	90	9
5	2	3	5 000	48	110	11
6	2	4	5 000	66	140	14

¹ Does not fulfil requirements.

Two curves with input voltage as abscissas and output current as ordinates with circuit 1 and one curve with circuit 2 are shown in Fig. 2. The irregularity of the sloping part indicates that the input current is distorted slightly by the amplifier due to the grid current taken by the tubes.

DISCUSSION

Table 1 shows that in order to fulfil the conditions that the input current of 10 to 20 milliamperes will be amplified to 110 to 200 milliamperes, the minimum number of tubes that can be used is four tubes in circuit 1 and 5 tubes in circuit 2. Circuit 1 should therefore be the more economical to use even though two separate filament batteries are required, because less tubes are required and the total current capacity of both batteries

FIG. 2—Amplifier characteristics

required to supply the filaments in circuit 1 is less than the capacity of the single battery required in circuit 2. Circuit 2 also requires an additional grid battery (B_6 , Fig. 1) of 12 volts.

The difference in amplification of the two circuits is due to the manner of connecting the coupling resistance (R_2 , Fig. 1). In circuit 1, the grid current of the second stage tubes acts as a regenerator, to increase the amplification for a given input current, while in circuit 2 the amplification is decreased by the grid current.

ADJUSTMENTS

The necessary adjustments to put the amplifier in proper operating condition are:

(1) Filament Current: The filament current is adjusted by means of a series rheostat to 2.3 amperes per tube, or the filament voltage to 7.4 volts. With an 8 volt storage battery and low resistance leads no external resistance is necessary.

(2) Output Current: With no input current flowing, the resistance R_3 of Fig. 1, is adjusted until the output current is reduced to zero. The amplifier is now ready for operation.

If changes occur in the plate voltage supply or a tube is replaced, it may be necessary to readjust R_3 to reduce the output current to zero with zero input current.

GENERAL

The plate supply (B_4 , of Fig. 1) may be of any voltage between 200 and 250 volts. A 220 volt D. C. light or power line may be used provided that the voltage does not vary more than about 10 volts.

With a plate supply of less than 200 volts the amplification decreases rapidly, while voltages in excess of 250 overheat the tubes and make their operation unsteady.

The above tests were all made using *UV-202* Radiotron 5-watt power tubes. Other tubes suitable for current amplification are Western Electric type *E* tubes. With these tubes somewhat less amplification was obtained, and not as steady operation because of heating.

SUMMARY

Two resistance-coupled amplifier circuits were constructed to amplify both a direct and alternating current of 10 milliamperes to 110 to 200 milliamperes magnitude, and tests made to determine the amplification for best adjustments of the circuit constants.

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