Mullard OUTLOOK TECHNICAL SECTION

# 'HARMONIOUS' RANGE OF AUDIO-FREQUENCY TRANSISTORS

A new range of audio-frequency transistors—the 'Harmonious' range—is being introduced by Mullard, and equipment using devices from this range will be appearing more and more frequently in the coming months. Applications of the transistors from this range extend from the smallest pocket and handbag portable radio sets to mains-powered tape recorders, record-players and radiograms. In this article we shall discuss several general amplifier circuits covering a range of outputs from 50mW to 6W. Subsequently we propose to consider more specialised applications such as tape recorder and input mixing circuits.

## MULLARD 'HARMONIOUS' RANGE

The 'Harmonious' range of audio-frequency transistors is being introduced to enable Mullard to offer a comprehensive solution to all audio amplifier problems. Six output transistors from this range will be considered in this article. These are grouped in matched pairs of p-n-p and n-p-n types giving output power coverage as follows:

Up to 1W: OC81 p-n-p plus AC127 n-p-n matched transistors forming the output pair of the audio package, type LFK4. The package is completed by an OC81D driver transistor and an AC127 pre-amplifier transistor.

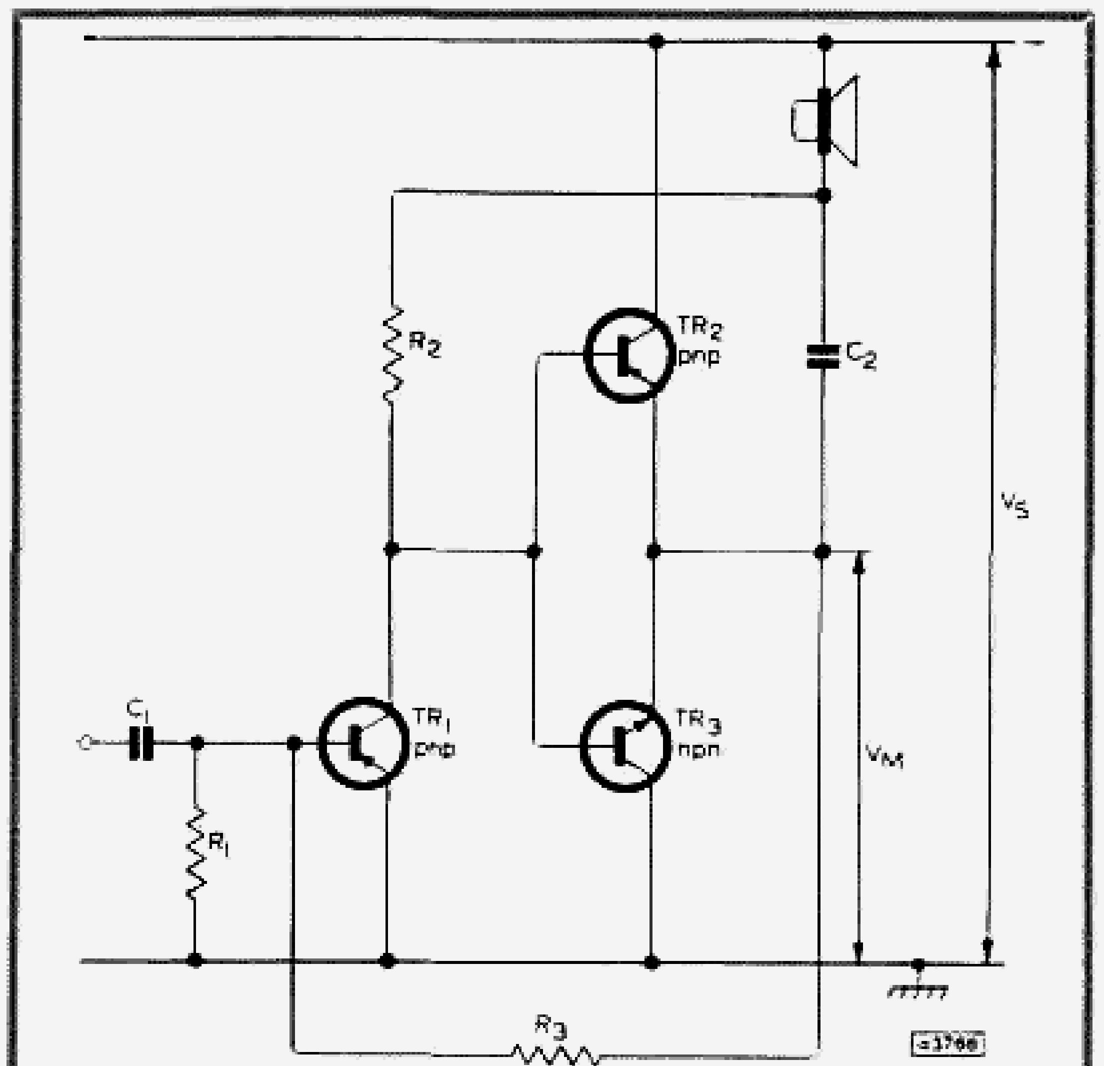


*Fig. 1—Basic circuit*

1 to 3W: AC128 p-n-p plus AC176 n-p-n matched output transistors.

3 to 6W: AD162 p-n-p plus AD161 n-p-n matched output transistors.

Audio stages producing output powers of up to 1W and utilising the LFK4 are likely to be encountered in battery-powered portable radio receivers, record players and tape recorders. Amplifiers employing either the AC128, AC176 pair or the AD161, AD162 pair and delivering up to 3 or 6W respectively are suitable for mains-powered applications such as record-players, tape recorders, table radios and console radiograms.

The pairing of p-n-p and n-p-n transistors enables complementary push-pull output stages to be designed. With this arrangement, driver and output transformers are unnecessary, and elimination of these components affords the benefits of:

(i) extended frequency response
(ii) improved transient response
(iii) ease in applying negative feedback
(vi) simplified layout
(v) reduced weight and bulk
(vi) savings in cost.

## AVAILABILITY FOR REPLACEMENT PURPOSES

Several of the transistors of the 'Harmonious' range are already available for replacement purposes. These are the OC81, OC81D, AD127 and AC128. The availability of the others mentioned above—the AC176, AD161 and AD162—will be announced in due course in OUTLOOK. It should be remembered that if a replacement is required for one transistor of a matched pair or any transistor of the LFK4 package, the transistor should be ordered individually by its type number and not as a matched pair or by the package number.

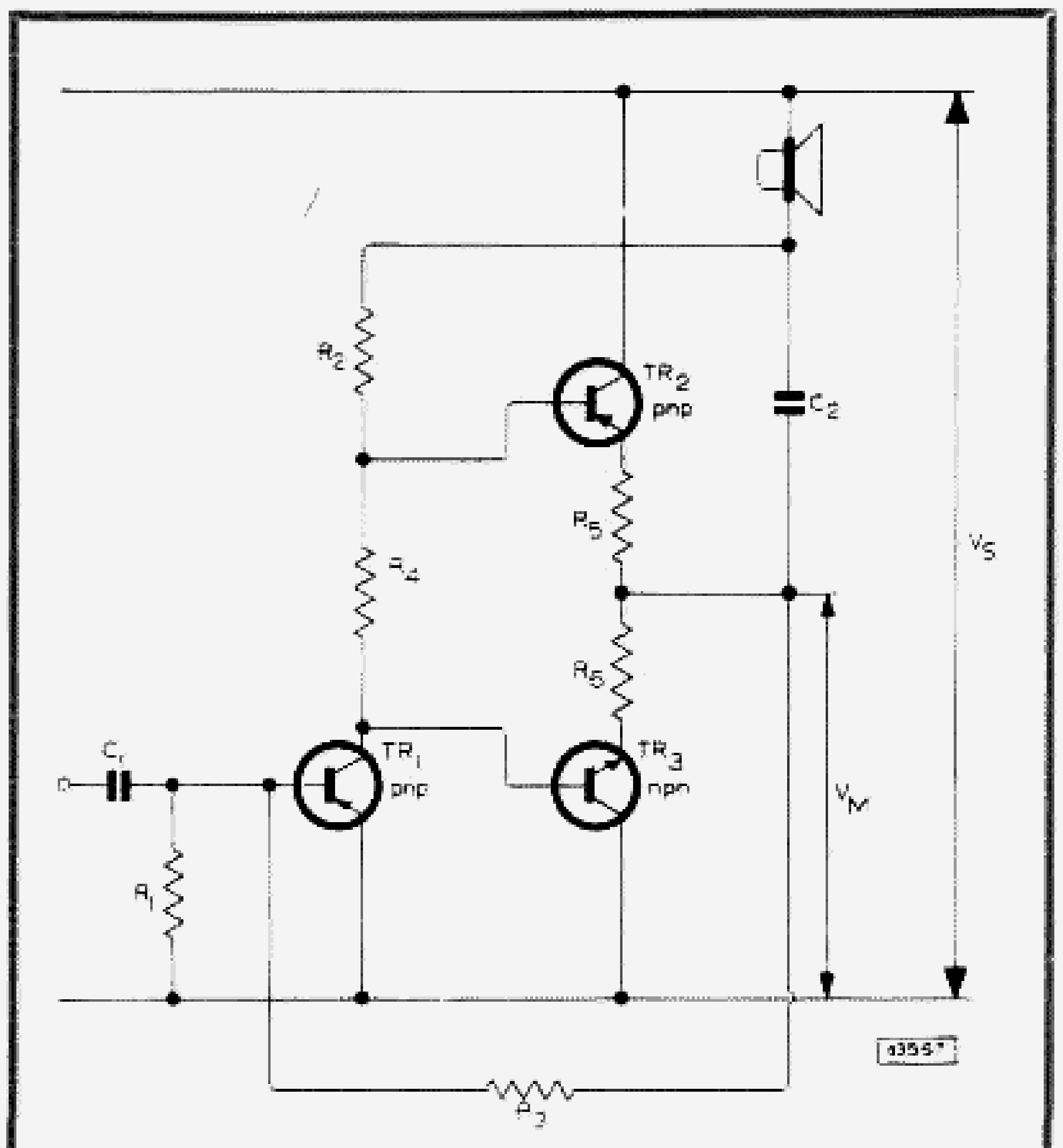


*Fig. 2—Biasing arrangement for basic circuit*

## COMPLEMENTARY PUSH-PULL AMPLIFIERS

Complementary push-pull amplifiers using p-n-p and n-p-n transistors can be explained in terms of the basic circuit of Fig. 1. The junction of the emitters of the output transistors $TR_2$, $TR_3$ is coupled to the loudspeaker via the capacitor $C_2$. The potential of this junction with respect to earth is $V_M$.

The signal from the driver transistor is applied simultaneously to the bases of the output transistors. During positive half-cycles, the n-p-n transistor $TR_3$ conducts, thus lowering the potential $V_M$, while during negative half-cycles, the p-n-p transistor $TR_2$ conducts and the potential $V_M$ is increased. These variations are applied to the loudspeaker by way of $C_2$.

The driver transistor $TR_1$ is directly coupled to the bases of the output transistors, and the collector load is returned to the 'live' terminal of the loudspeaker.* Since this point is a.c. coupled to the emitters of the output transistors, the signal is effectively applied between the base and emitter of each output transistor. D.C. and a.c. feedback is applied by means of resistor $R_3$.

Because of the voltage drop across the driver stage (the bottoming voltage of

* *Alternatively, the collector load is decoupled to the 'live' terminal, as shown in Fig. 5.*

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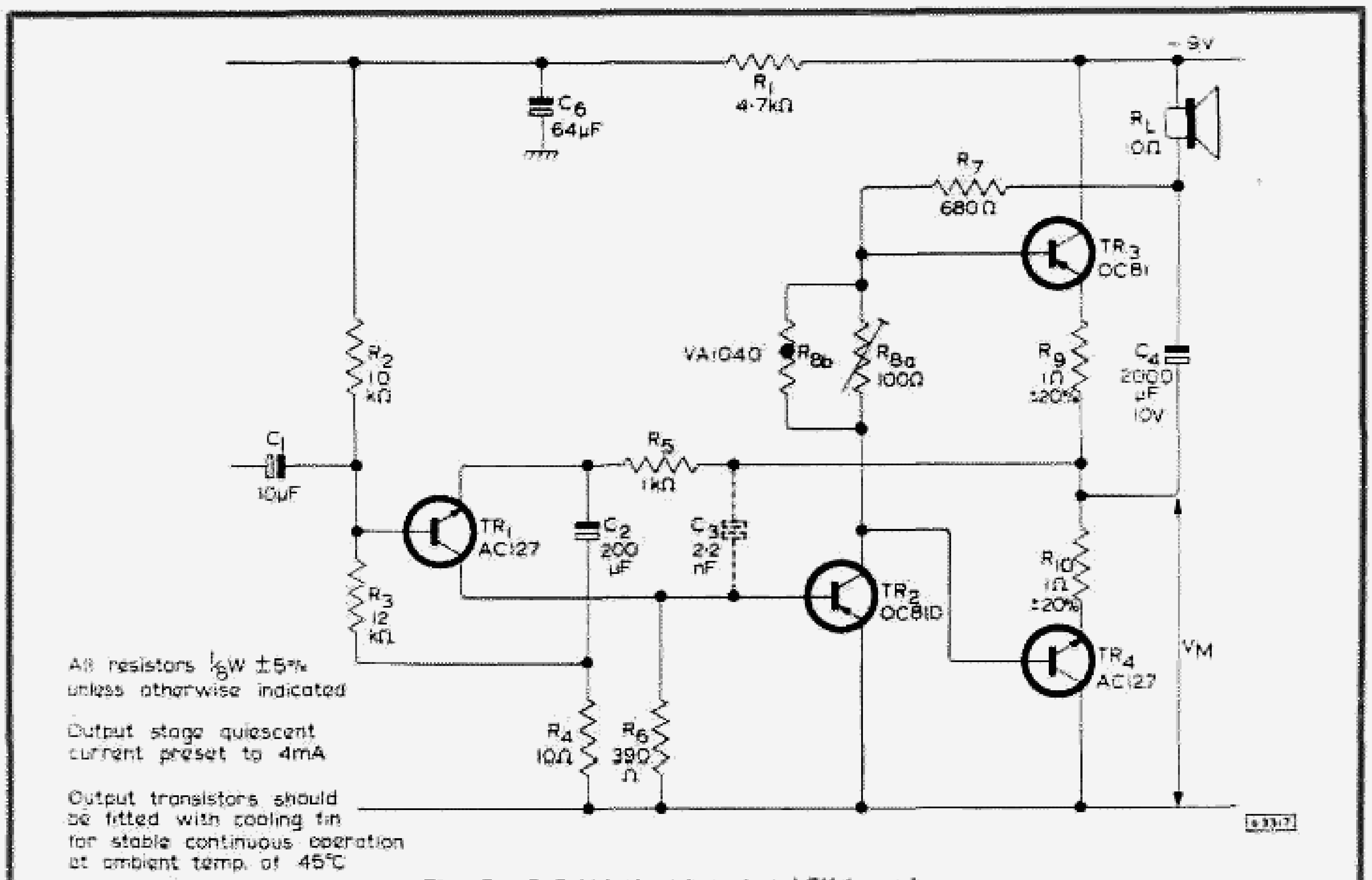


*Fig. 3—2·5 W circuit using LFK4 package*

$TR_1$), the maximum positive excursions of the output voltage in Fig. 1 will be less than the maximum negative excursions if $V_M$ is half the supply voltage $V_S$. To obtain approximately equal positive and negative voltage swings, it is necessary to make $V_M$ slightly more than $\frac{1}{2}V_S$.

### Practical Biasing Arrangement

In a practical circuit, the quiescent bias voltage for the output transistors is produced by the voltage developed across a resistor placed in the collector circuit of the driver transistor. The method of connection is shown in Fig. 2. Since the value of this resistance $R_4$ is much smaller than that of $R_2$, its inclusion will not introduce any significant unbalance in the output. Resistors $R_5$ and $R_6$ are included in the emitter circuits of the output transistors to improve thermal stability.

Crossover distortion occurs in class B amplifiers when the transition from conduction by one output transistor to conduction by the other is not smooth. The combined transfer characteristic is then not linear, but has a discontinuity (or variation in slope) at the changeover point. This type of distortion produces a highly objectionable audible effect which is peculiar to class B amplifiers.

Crossover distortion can be removed by biasing the transistors to give a linear combined transfer characteristic. For a given output stage, an optimum bias condition (and also quiescent current) exists for which the crossover distortion is minimum. Changes in supply voltage or ambient temperature, however, will cause departures from this optimum and therefore increased crossover distortion.

The quiescent current required for the optimum bias condition is obtained by a suitable choice of bias resistance. Considerable spreads about the nominal current will result, however, from tolerance spreads in resistor values and transistor characteristics and from variations in ambient temperature and supply voltage.

The effects of changes in component spreads can be minimised by individually setting the bias by means of a preset resistor in place of $R_4$. The effects of temperature changes can be minimised by the use of a thermistor in conjunction with the biasing resistor. The effects of supply voltage changes can be minimised by means of a diode or other stabilising device from which the bias can be derived.

## ILLUSTRATIVE CIRCUITS

Three practical circuits are discussed below which employ the complementary push-pull technique and illustrate the range of amplifiers that can be constructed using the combinations of transistors listed above.

## BATTERY-POWERED AMPLIFIERS

The circuit for an 0·5W battery-powered amplifier using the LFK4 package is given in Fig. 3. In the LFK4 audio package, the matched pair, types OC81 and AC127, forms the transformerless output stage. This stage is preceded by an OC81D driver stage and an AC127 pre-amplifier. The output and driver stages are based on Fig. 2.

The load is capacitively coupled to the emitters of the output transistors. The bases of $TR_3$ and $TR_4$ are driven directly from the collector of $TR_2$. The collector load $R_7$ of $TR_2$ is connected to the 'live' terminal of the speaker so that $TR_3$ and $TR_4$ operate in the grounded-emitter configuration, thus giving maximum gain. The small quiescent bias voltage required for transistors operating in class B push-pull is developed by the collector current of $TR_2$ flowing through $R_8$.

The pre-amplifier transistor $TR_1$ also acts as a d.c. amplifier, comparing the voltage at its base with the mid-point voltage $V_M$ of the output stage. The high loop gain of the circuit fixes the d.c. value of $V_M$ with respect to the base voltage of $TR_1$, thus reducing the effects of temperature variations and transistor and resistor spreads.

Overall a.c. negative feedback is applied to the emitter of $TR_1$, the feedback voltage being defined by the potential divider $R_4$, $R_5$.

The circuit is d.c.-coupled throughout which reduces the number of components and affords an extended frequency response and good transient response. The driver can be run at a low quiescent current, so that

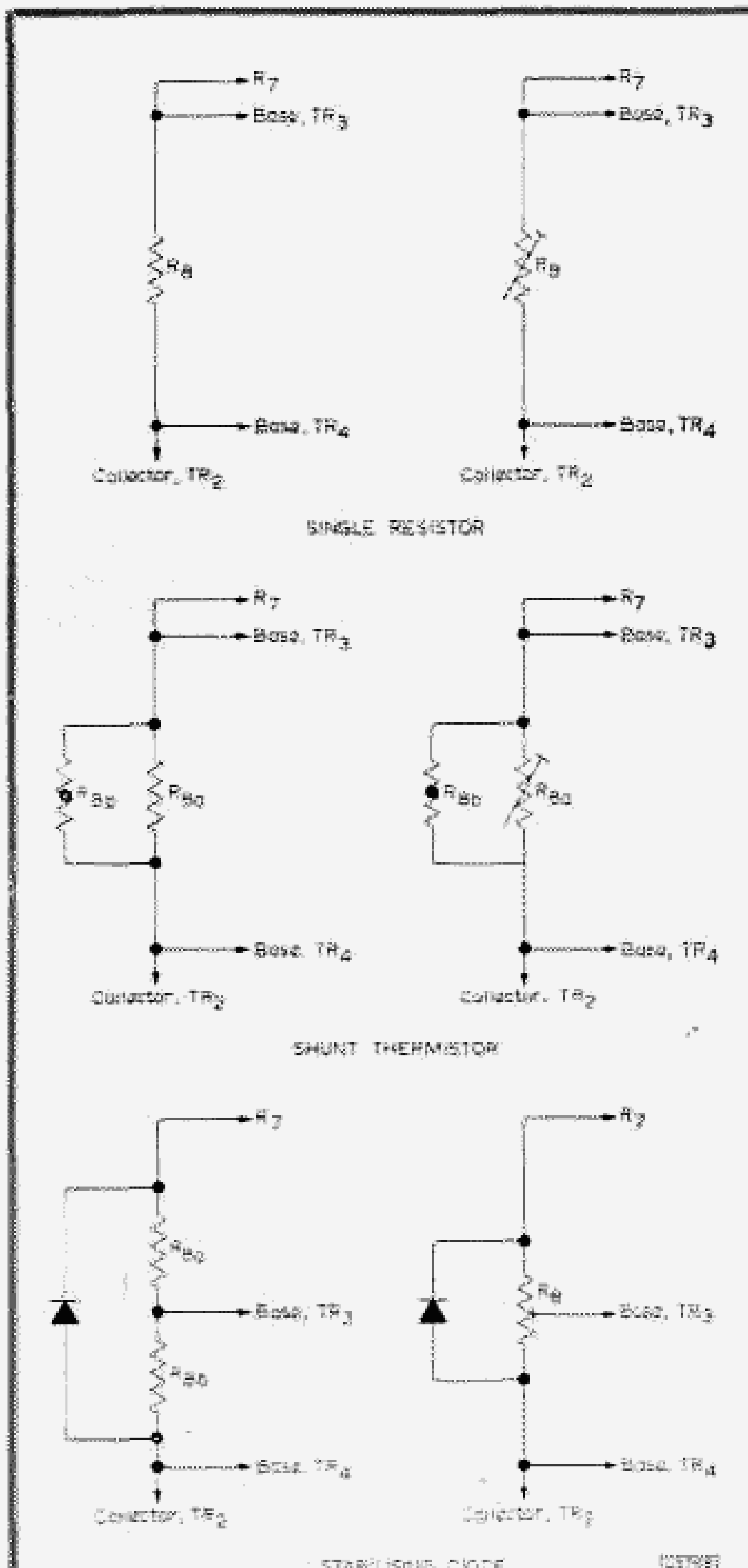


*Fig. 4—Alternative biasing networks for Fig. 3*

battery consumption is minimised. The performance of the circuit is summarised as follows:

- Battery voltage (stabilised) 9V
- Output power 0·5W
- Sensitivity (open-circuit e.m.f. of 2kΩ source)
  - for 0·5W: 45mV
  - for 50mW: 14mV
- Frequency response (−3dB): 100c/s to 10kc/s
- Distortion at 0·5W: <5%
- Total battery drain 11mA

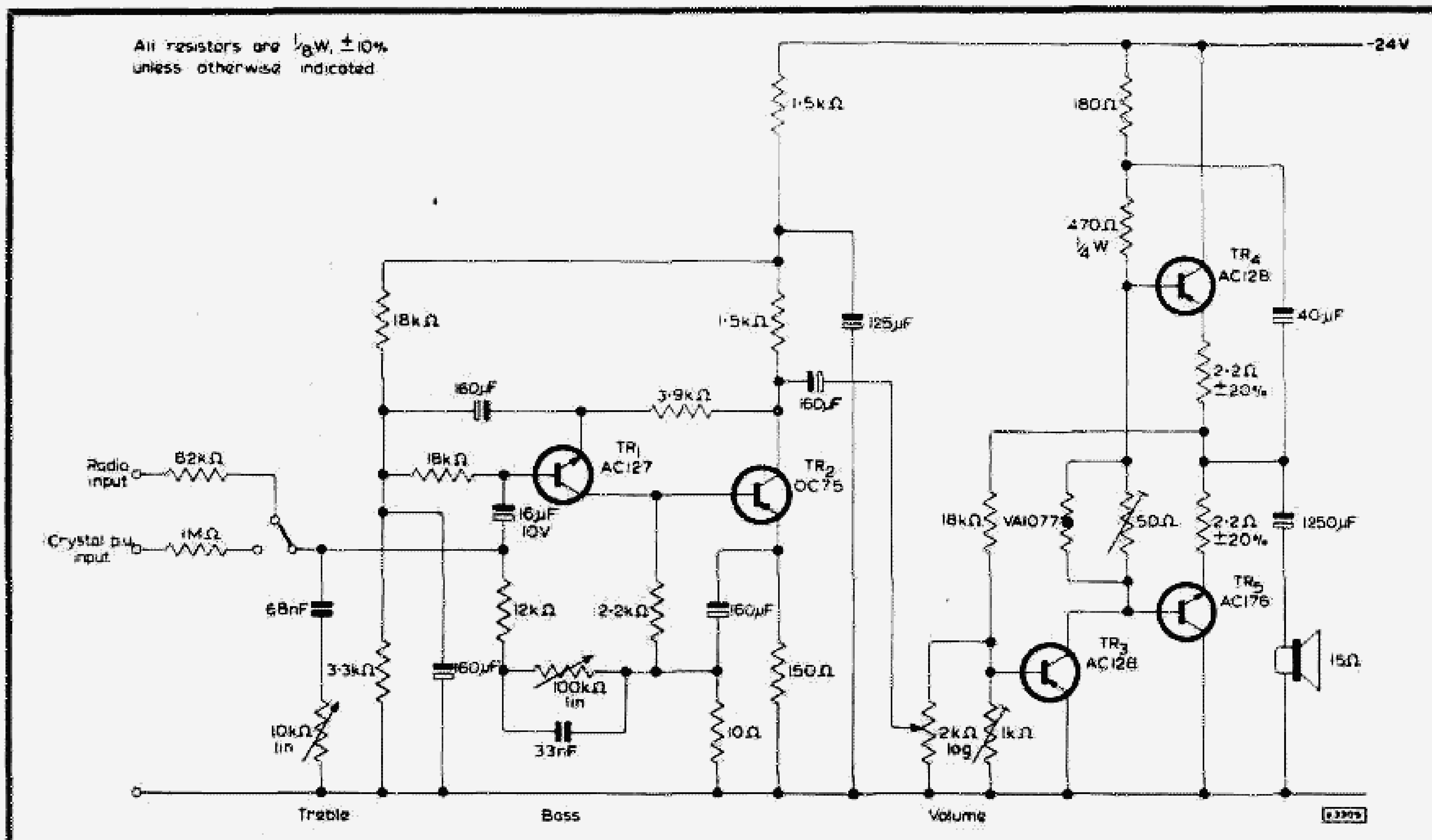


*Fig. 5—3W circuit using AC128, AC176 output pair*

### Variants

The LFK4 package affords flexibility of design, and a range of variants of the circuit of Fig. 3 are possible. The circuit values that can be varied are the supply voltage, output power, biasing arrangement for the output transistors, and the value of emitter resistor and bypass capacitor of the driver transistor (omitted in Fig. 3).

The choice of supply voltage is related to the output power required. The range of possible voltages is the practical battery voltage range of 6 to 12V. The maximum power attainable at 6V is 400 mW, at 9V, 750mW, and at 12V, 1W.

The sensitivity for a given output power does not increase very rapidly with increasing battery voltage in a particular configuration. However, significant increases in sensitivity can be achieved by the use of an emitter resistor in the driver stage. This is more effective and more practicable at higher battery voltages. The resistor (and bypass capacitor) are omitted in Fig. 3 for reasons of economy and efficiency. Inclusion of these components can cause a slight loss in output power, but an increase in sensitivity and reduction in distortion can be obtained.

The quiescent current of the output stage is determined by the voltage between the bases of $TR_3$ and $TR_4$ produced by the driver current flowing in the bias network. An ideal bias arrangement would ensure a constant quiescent current in the output transistors irrespective of temperature and battery voltage variations and component spreads.

In practice, the degree of crossover distortion and the values of the emitter resistors $R_9$ and $R_{10}$ required for thermal stability depend on how near to the ideal the actual bias network is. High emitter resistors give poor power efficiency and loss of output.

Biasing networks that may be encountered are shown in Fig 4. The use of a simple fixed resistor without d.c. feedback may give a wide variation in output powers. A preset resistor by which allowance can be made for component and transistor spreads offers a more efficient design. In both cases, crossover distortion will be present under extremes of temperature and battery voltage variations, the onset being somewhat delayed when a preset resistor is used.

A shunt thermistor may be used to compensate for the temperature dependence of the quiescent current, and this arrangement will give acceptably low crossover distortion over a wide range of temperatures. A stabilising diode may be used to prevent bias changes with supply voltage. The use of preset resistors is likely in conjunction with thermistors or diodes, as the latter components increase the problem of spreads. A half-way stage between the use of a preset bias control and a fixed resistor may be encountered in which a combination of series resistors is used, one or more of which can be short-circuited.

### MAINS-POWERED AMPLIFIERS

Circuits for 3W and 5W amplifiers intended for operation from a mains power supply are given in Figs. 5 and 6 respectively.

For mains-powered operation, the loudspeaker is returned to the chassis, instead of the h.t. line as in the battery-powered circuit, to prevent any ripple that may be present from appearing directly across the speaker.

To provide common-emitter drive for the output transistors, the collector load of the driver transistor is tapped, the tapping point being capacitively coupled to the mid-point of the output stage*. The mid-point voltage is stabilised by d.c. feedback to the base of the driver transistor, and a 1kΩ preset resistor is used to accommodate component tolerances and transistor spreads. This preset resistor also provides a.c. feedback, which reduces distortion and gain spreads originating in the output stage.

The thermistor stabilises the quiescent current of the output stage and the 50Ω preset resistor is used to set-up the initial current.

As the d.c. voltage at the base of the driver transistor is low (approximately 0·2V) the volume control is connected directly to this point, thus eliminating the need for a coupling capacitor.

As the output stage of these amplifiers is a class B push-pull circuit, the heatsink can be considerably smaller than would be required for class A circuits. The average current required from the power supply is also considerably lower. Transistors $TR_4$ and $TR_5$ should be mounted on a heatsink having an area not less than $35cm^2$ per

[*continued on page 8*

**This arrangement is chosen in preference to that of Fig. 1 because of its lower sensitivity to hum on the h.t. line.*

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transistor. The driver transistor $TR_3$ should be mounted in a clip.

One n-p-n and one p-n-p transistor are directly coupled to form the pre-amplifier. The working currents are stabilised by d.c. feedback from the collector of $TR_2$ to the emitter of $TR_1$. Negative feedback is applied from the emitter of $TR_2$ to the base of $TR_1$. The bass boost control operates by reducing this feedback at low frequencies. A passive treble cut control is also provided at the input.

Switched resistors in series with the input are used to obtain the required input impedance and sensitivity for radio and crystal pick-up operation.

Alternative circuits based on the configuration of Fig. 3 are possible. Such a four-transistor circuit by itself is sufficiently sensitive for high-output crystal pick-up heads only. For general radiogram use, it must be preceded by an extra pre-amplifier stage.

### Circuit for AC128, AC176 Output Pair

The AC128, AC176 circuit illustrated in Fig. 5 is designed for operation with a power supply having an internal resistance of 20Ω. Use is made of the fact that current consumption with a speech and music input is considerably less than with a sine-wave input. As a result, the attainable power is higher with the speech and music drive than with the sine-wave drive.

Three output power figures are given:

(i) the speech and music rating, which indicates the equivalent sine-wave output that will be obtained when peaks occur in low-level passages of speech or music;

(ii) the sustained music rating which is the equivalent sine-wave output that will be obtained during sustained high-level passages of music;

(iii) the normal sine-wave rating.

The first two figures constitute a useful measure of the practical output-power capability of the amplifier. The third indicates the power to be obtained when the amplifier is being tested with a sine-wave drive. The performance of the amplifier can be summarised as follows:

| | |
|---|---|
| Output power | |
| for speech and music: | 3W |
| for sustained music: | 2·7W |
| for sine-wave: | 2·2W |
| Sensitivity | |
| at rated output | |
| (i) radio: | 45mV |
| (ii) crystal pick-up: | 550mV |
| at 50mW | |
| (i) radio: | 5·5mV |
| (ii) crystal pick-up: | 70mV |
| Input Impedance | |
| (i) radio: | 82kΩ |
| (ii) crystal pick-up: | 1MΩ |
| Treble cut (max): | 10dB at 8kc/s |
| Bass boost (max): | 9dB at 50c/s |
| Distortion at rated output: | <5% |

It is important that the power supply resistance should not be lower than 20Ω if heatsinks with the published value of thermal resistance are to be used.

### Circuit for AD161, AD162 Output Pair

For applications in which outputs of from 3 to 6W are required using sine-wave drive, the circuit illustrated in Fig. 6, using the AD161, AD162 output pair is suitable. The performance quoted assumes a supply of negligibly low internal resistance.

The performance can be summarised as follows:

| | |
|---|---|
| Output power (sine-wave or speech and music): | 5W |
| Sensitivity | |
| at rated output | |
| (i) radio | 55mV |
| (ii) crystal pick-up: | 700mV |
| at 50mV | |
| (i) radio: | 5·5mV |
| (ii) crystal pick-up: | 70mV |
| Input Impedance | |
| (i) radio: | 82kΩ |
| (ii) crystal pick-up: | 1MΩ |
| Treble cut (max): | 10dB at 8kc/s |
| Bass boost (max): | 9dB at 50c/s |
| Distortion at rated output: | <5% |

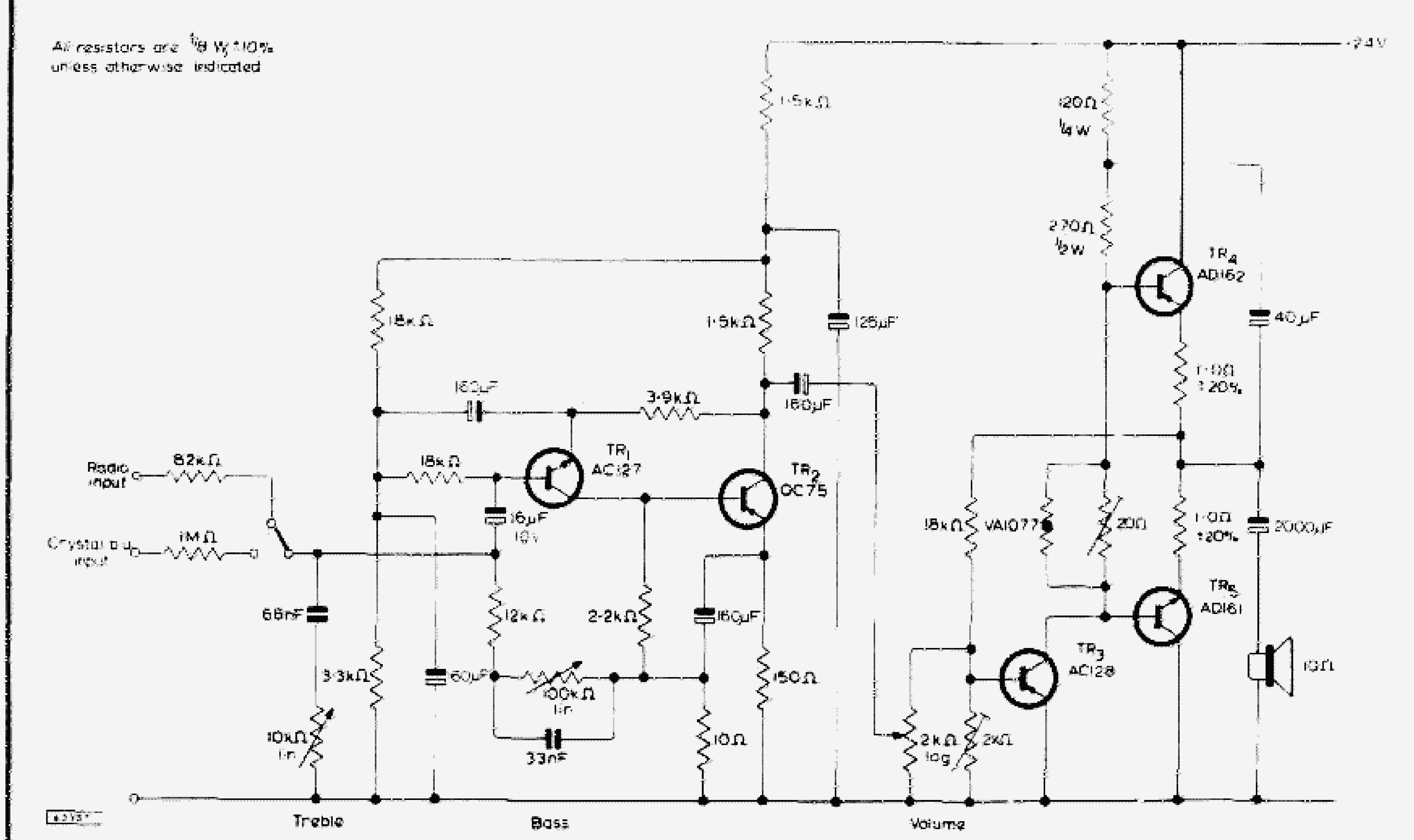


*Fig. 6—5W circuit using AD161, AD162 output pair*