LB-1054

A SIX-TRANSISTOR PORTABLE RECEIVER EMPLOYING A COMPLEMENTARY SYMMETRY OUTPUT STAGE

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Approved

Stuart W. Seeley

The principle of complementary symmetry in transistor circuits has been recognized for a number of years as affording advantages of simplicity of circuitry and economy of components. Certain unique problems arise in integrating a complementary symmetry audio amplifier with the *r-f* and *i-f* circuits of a broadcast receiver.

The receiver described in this bulletin features audio, volume-control, and *a-g-c* circuitry which leads to the practical realization of the inherent advantages of complementary symmetry. The receiver circuit is described, and its performance characteristics are compared with those of a typical commercial receiver, which utilizes a conventional transformer-coupled audio amplifier.

Introduction

The experimental receiver described in this bulletin was constructed to obtain an evaluation of a system using a complementary symmetry class-B audio output stage in comparison with a more conventional transformer-coupled arrangement. This receiver offers advantages of simplicity, and of economy of transistors and components. Its performance characteristics in some respects differ from those of typical commercial receivers, principally due to a different distribution of gain among the antenna, r-f and i-f circuits, and the audio amplifier. The over-all impression of the performance of the receiver, obtained in comparative field tests with various commercial receivers, is favorable. Six transistors are employed, three in the r-f and i-f portion of the receiver, and three comprising the audio and a-g-c amplifier. The output stage drives the 50-ohm voice coil of the 4-inch loudspeaker directly; no audio transformers are employed.

The basic circuit principles utilized in the r-f and i-f circuits[1] and in the audio amplifier[2] have been described previously. The development here has been focused on the integration of a complementary symmetry audio circuit with a conventional r-f and i-f circuit.

The receiver breadboard is packaged in a wooden cabinet, as shown in Fig. 1, to facilitate field testing. No attempt has been made to miniaturize or to otherwise provide a more finished unit.

The receiver is intended to operate from a battery in the 9 to 13.5-volt range. A number of the receiver performance characteristics, using both 9 and 13½-volt batteries, are summarized in Table I. (The 9-volt data are

[1] *LB-1014, Stability Considerations in Transistor IF Amplifiers* by T. O. Stanley and D. D. Holmes.

[2] *LB-1021, Design Considerations in Class B Complementary Symmetry Circuits* by T. M. Scott and T. O. Stanley.

TABLE I

	Experimental Receiver		Conventional Receiver
	9-volt Battery	13½-volt Battery	9-volt Battery
Sensitivity (5 mw)	250 μv/m	130 μv/m	130 μv/m
Idling Current	8.5 ma*	14 ma*	8 ma
Max Power Output (10% Distortion)	180 mw	430 mw	230 mw
Agc Fig. of Merit (50K μv/m Reference)	45 db	46.8 db	28.6 db
Signal for 20 db S/N	140 μv/m	140 μv/m	500 μv/m

* These are average characteristics. The manner in which idling drain varies as a function of volume-control setting and carrier level is shown in Fig. 7.

indicative of battery end-point performance, using a 13½-volt battery.) Similar characteristics for a conventional transistor receiver employing a transformer-coupled audio amplifier are given for reference.

Circuit Description

A schematic diagram of the receiver is shown in Fig. 2. Transistor V1, RCA 2N140, serves as the converter; V2 and V3, RCA 2N139's, are employed as first and second i-f amplifiers; V4, RCA 2N109, is the audio driver and a-g-c amplifier; V5 and V6, RCA 2N109 and Sylvania 2N35 respectively, comprise the class-B complementary symmetry output stage. A 1N295 crystal diode performs the second-detector function.

The signal circuits associated with the first three transistors are substantially the same as those recommended in the 2N140 and 2N139 data sheets,[3] and will not be described in detail here. The audio output stage, employing essentially an emitter-loaded configuration, has been described in *LB-1021*[2]. In this bulletin it was pointed out that the advantage of simplicity of a complementary symmetry circuit over a transformer-coupled arrangement is accompanied by approximately a 12 db disadvantage in receiver gain. The receiver described here employs a relatively large (¼ × ¾ × 7) ferrite rod antenna, which in part offsets the gain disadvantage, and at the same time enhances the receiver signal-to-noise ratio. The design of the i-f transformers is based on procedures described in *LB-1014*[1] which lead to maximum i-f gain commensurate with manufacturing tolerances on transistor feedback capacitance.

Audio Amplifier

The output of the second detector is direct-coupled to the audio driver and a-g-c amplifier, V4. An initial forward bias for the detector diode and for V4 is provided by the resistance network comprising R7, R8, and R9, which returns to the negative supply. The driver d-c load consists essentially of the parallel combination of R1-R2, R5-R6, and R4 (the loudspeaker voice-coil resistance is negligible with respect to these resistances). The driver d-c collector current is stabilized (1) by the detector diode and (2) by d-c collector-to-base feedback introduced by the biasing and load arrangement. With respect to (2), an increase in collector current will produce an increased voltage drop in the d-c load resistance, thereby reducing the effective collector-to-emitter supply voltage and the amount of forward bias applied between base and emitter.

[3] Alternatively, one might consider using the RCA 2N247 drift transistor in the converter and i-f amplifier stages (with suitable circuit modifications). The performance of the RCA 2N247 transistor in converter and i-f amplifier circuits is described in *LB-1045, A Drift Transistor for High Frequency Applications;* the use of drift transistors in the first three stages of the receiver described here should result in a 10-15 db increase in gain. The choice of a transistor type would then be based upon the usual cost-performance considerations.

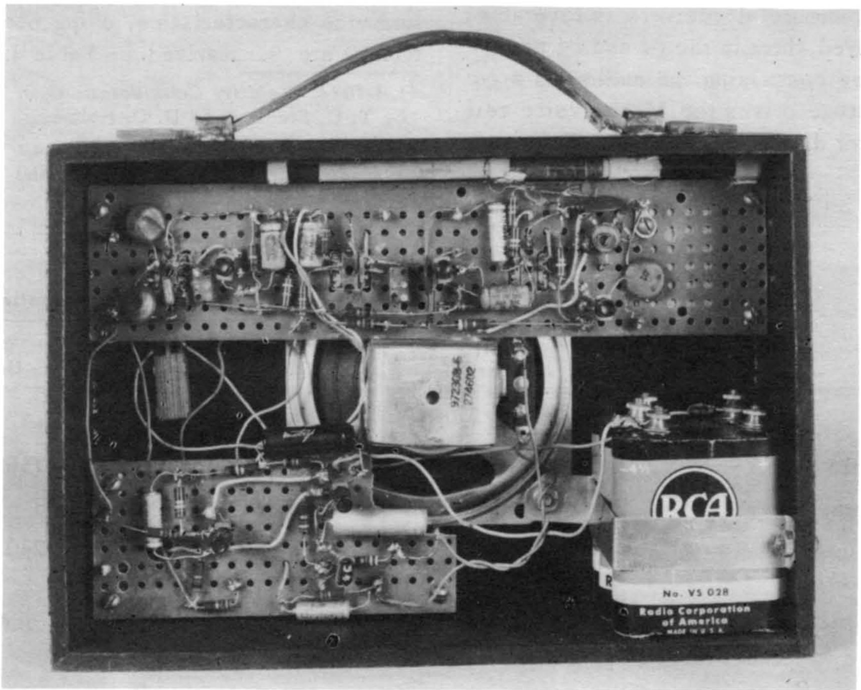

Fig. 1 – Rear view of experimental receiver.

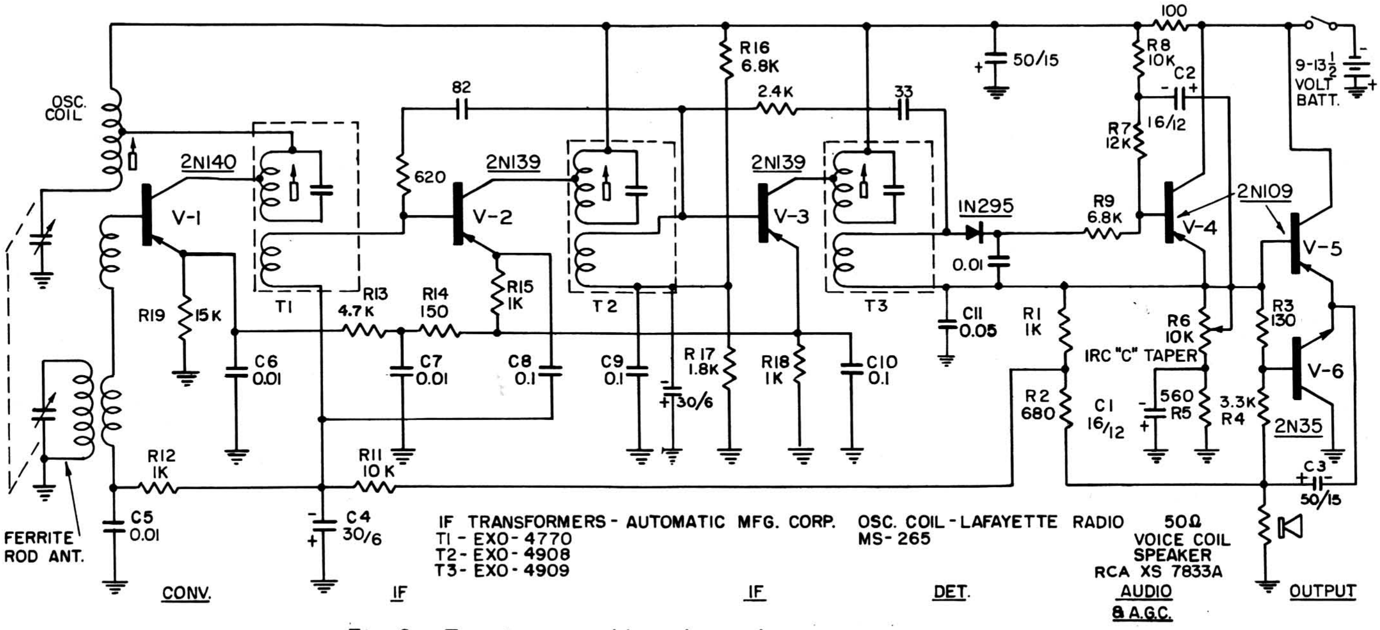

Fig. 2 – Transistor portable with complementary symmetry output.

The output of the second detector is applied between base and emitter of the driver, while audio output is taken from the driver emitter. Capacitor C2 returns the base bias supply to the emitter for signal so that no signal degeneration is introduced. The driver, then, is connected in an *emitter-loaded* configuration.

The driver output is direct-coupled to the output stage which, in turn, is capacitively coupled to the 50-ohm voice coil of the loudspeaker. Referring to the driver-output stage coupling network, at maximum volume-control setting (max. resistance) the resistance of the volume control can be neglected, since it is high compared to the parallel combination of R1-R2 and R4. These two resistances return to the high side of the loudspeaker voice coil so that only the base-to-emitter voltage of the output stage need be developed across them. Little signal current is wasted in the driver coupling resistance by virtue of this arrangement. At maximum volume control setting, then, the output stage also operates as an *emitter-loaded* configuration.[4]

Threshold bias for the output stage is developed across R3. The substitution of a parallel resistor-thermistor network for R3 can provide effective temperature compensation for the output stage quiescent collector current.[2]

High-frequency roll-off in the audio amplifier is controlled by capacitor C11 which introduces negative feedback in the output stage at frequencies above approximately 2500 cps. This capacitor also serves as an i-f ground return for the secondary of the third i-f transformer.

AGC

The d-c output of the second detector is amplified by the audio driver; a-g-c voltage is taken from the junction of R1 and R2 at the driver output, filtered by R11 and C4, and applied to the bases of the converter and first i-f stages. The polarity of the second detector diode is such that the driver d-c collector current decreases with increasing signal; the d-c voltage at the junction of R1 and R2, therefore, becomes less negative with increasing signal, and when applied to the bases of the controlled stages, produces the desired reduction in collector current.

The biasing arrangement of the second i-f stage maintains a substantially constant current through resistor R18. The drop across R18 (approximately 2 volts) is utilized as a constant-voltage reference for the gain-controlled stages. This obviates the need for a separate relatively high-current bleeder or a battery tap. The emitter of V2 returns via R15 to this point. When the a-g-c voltage becomes less than approximately -2 volts, V2 is substantially cut off.

The emitter of V1 returns to ground via R19 and to the emitter of V3 via R13 and R14. Resistor R19 provides sufficient bias for V1 that oscillation does not cease under strong signal conditions, i.e., when a-g-c action reduces the current in R13 to zero. A conversion gain control range of approximately 10 db is afforded by this arrangement. The converter is decoupled from the emitter

[4] This type of circuit has been employed in apparatus or circuits described in the following bulletins: *LB-957, A Developmental Pocket-Size Broadcast Receiver Employing Transistors; LB-1021, Design Considerations in Class-B Complementary Symmetry Circuits; LB-1022, Transistor Audio Amplifiers; LB-1027, A Transistor Phonograph Amplifier Using a Quasi-Complementary Circuit.*

of V3 by R14 and C7, and from the base of V2 by R12 and C5.

When the collector currents of V1 and V2 are reduced by a-g-c action, the collector current of V3 increases in like amount (approximately 1 ma), since the bias arrangement of V3 tends to hold the current in R18 constant; the signal-handling capability of V3, under strong-signal conditions, is therefore increased.

The a-g-c system acts to keep the d-c voltage at the driver emitter at a value approximately equal to one-half the battery voltage. Clipping in the audio amplifier is then nearly symmetrical at maximum output. The i-f signal level at the input to the second detector is controlled in part by the volume control through its reaction on the a-g-c level, as described in the following section.

Volume Control

The volume control consists of a variable resistor, R6, in the emitter circuit of the driver; this control performs several functions. At maximum volume setting, substantially all of the driver output signal current flows into the output stage bases. As the control is reduced, signal is diverted to ground via C1, and negative feedback is introduced in the output stage. Appreciable feedback is introduced when the resistance of the volume control becomes comparable to or less than the resistance of the parallel combination of R1-R2 and R4, since the volume control returns to ground (via C1) rather than to the high side of the loudspeaker voice coil. At very low volume settings, the output stage effectively operates as a common-collector circuit.

As the volume control is reduced, the effective collector-to-emitter supply voltage of the driver increases, tending to increase the driver d-c collector current. Resistor R5, in series with the volume control, serves to limit this increase to approximately 9 ma at minimum volume (using a 13½-volt battery).

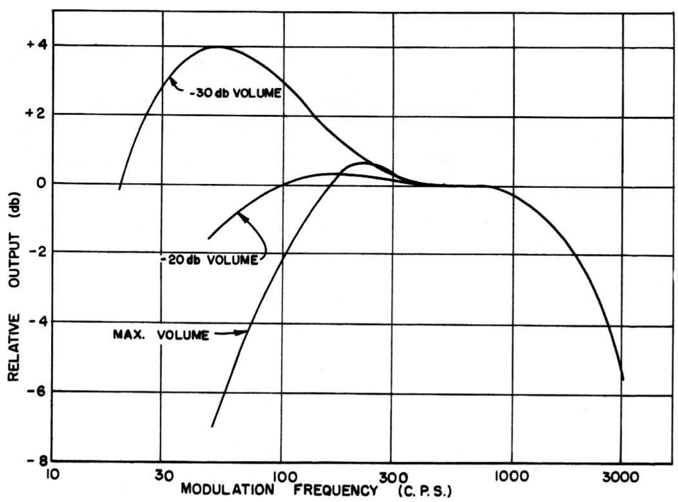

Fig. 3 – Electric fidelity for three volume control settings.

A tone-compensated volume-control effect is obtained by virtue of C1, which is a relatively poor by-pass at low frequencies. The effect of volume control setting on electric fidelity is shown in Fig. 3. At -20 db and -30 db volume setting, the response at 50 cps is boosted 6.5 db and 11 db respectively.

Clipping in the audio amplifier at maximum output can only be produced by providing sufficient i-f input to the second detector that collector bottoming occurs in the driver on negative peaks and in the 2N35 output transistor on positive peaks. To obtain clipping at maximum volume setting, the volume control is arranged to react on the a-g-c circuit in such a manner that as the control is advanced, the i-f level at the input to the second detector is increased. This follows from the fact that the driver d-c load resistance is proportional to the volume-control setting; for a given driver collector current, the a-g-c voltage becomes more negative as the volume control is advanced. Adjustment of the volume control from maximum to minimum reduces the detector input level by approximately 10 db. For signal levels greater than 1.0 mv/m hard clipping can be obtained in the audio amplifier by setting the volume control at maximum; at 1.0 mv/m, the onset of clipping occurs at 80 percent modulation; at 10 mv/m and higher it occurs at approximately 60 percent modulation.

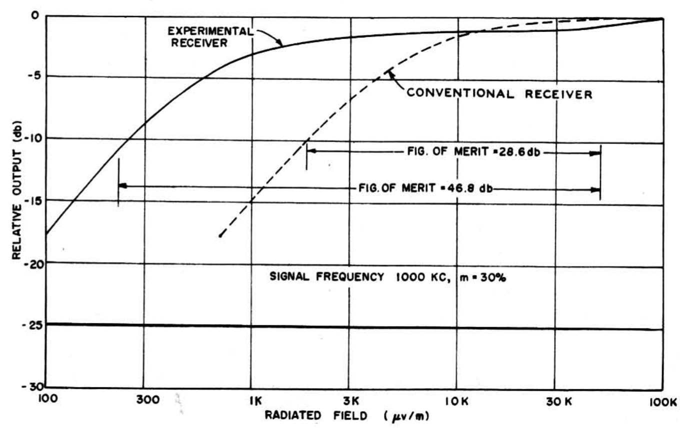

Fig. 4 – A-G-C characteristics.

Performance

The performance of the receiver with respect to a-g-c, r-f and i-f overload, and audio distortion is shown in Figs. 4, 5 and 6. Similar characteristics for a typical conventional transistor receiver are shown for reference.

Relatively high (86 db) rf-if gain, a large ferrite rod antenna, amplified a-g-c, and application of a-g-c to the converter conspire to provide a relatively high (46.8 db) a-g-c figure of merit, as shown in Fig. 4

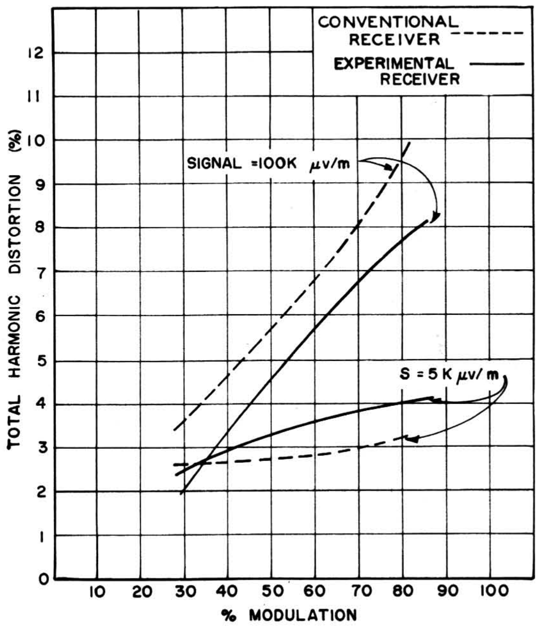

Fig. 5 – Distortion vs percent modulation for medium and strong signal levels.

The strong and medium-signal distortion of the receiver, illustrated by Fig. 5, is not unlike that of the conventional receiver. Despite the larger ferrite antenna, overload occurs at approximately the same signal level by virtue of 10-db gain control obtained in the converter.

Distortion-vs-power-output characteristics are shown in Fig. 6. Maximum output is 180 mw, using a 9-volt battery, and 410 mw, using a 13½-volt battery. The conventional receiver, which utilizes a 9-volt battery, produces a maximum output of 235 mw.

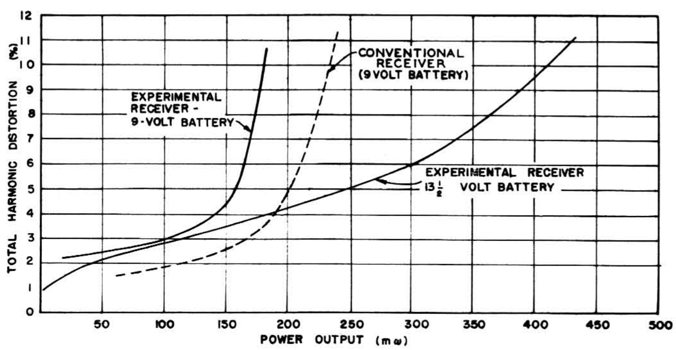

Fig. 6 – Distortion vs power output using 9 and 13-½ volt battery.

The idling current drain, for minimum and maximum volume control setting, as a function of carrier level is shown in Fig. 7. Under typical listening conditions, the average idling current drain is about 14 ma and 8.5 ma, using 13½-volt and 9-volt batteries respectively.

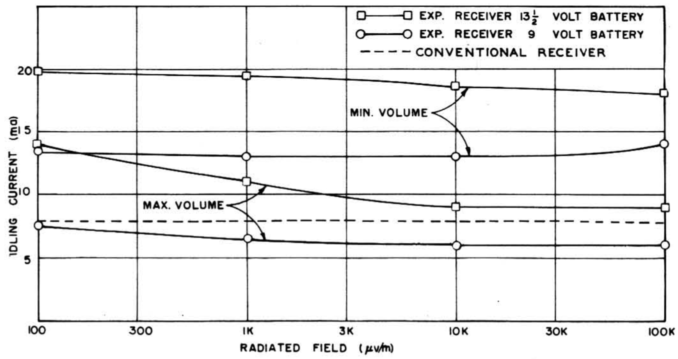

Fig. 7 – Idling current drain characteristics (m = 0%).

Discussion

This receiver represents one group of compromises associated with the application of a complementary symmetry audio amplifier to a portable broadcast receiver. Other compromises among battery life, power output, gain, loudspeaker voice-coil impedance, etc., may be desirable from an economic or performance standpoint.

One important advantage gained through the elimination of audio transformers is not apparent from inspection of the distortion characteristics. This is a freedom from ringing of transformer leakage reactance which is likely to occur when current switches from one output transistor to the other. Ringing produces high-order harmonics which do not contribute a significant amount to the total harmonic distortion figure, but which can be objectionable to the listener.

John O'Connell

David D. Holmes