Direct Conversion A Neglected Technique

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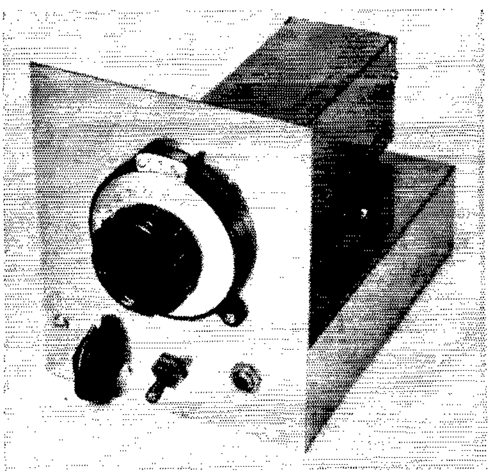
An amateur activity of increasing popularity is the construction of small, compact equipment for portable operation. Certainly a review of recent amateur literature will reveal significant interest in rigs of the pocket or rucksack variety. Although the construction of a simple solid-state transmitter with an input of a few watts presents no obstacles to the experimenter with minimal experience, the fabrication of a suitable companion receiver does impose some problems. The portable receivers typically in use are of the regenerative type, the regenerative superhet, or a tunable converter operated ahead of a broadcast band superhet. While all of these techniques have the distinct advantage of simplicity, the results obtained are frequently less than optimum, especially when strong signals are encountered.

Another approach to the portable receiver design problem is the direct conversion technique. Basically the direct conversion method involves the applying of the desired r.f. signal and a local oscillator signal to a product detector. The beating of the two signals produces an audio-frequency signal which needs only further amplification in order to be heard.

Examination of the detection process reveals that the true product detector is a linear device.[1] Its output amplitude is nearly proportional to the input signal for all signals of small amplitude as compared to the b.f.o. signal. In any linear system selectivity may be obtained at either a.f. or r.f. In this case the receiver's selectivity was obtained at audio frequencies by a low-pass filter which is used to eliminate all frequency components above a specified cutoff (about 2 kHz.). A simple, high-gain audio amplifier following the audio filter completes the receiver.

A direct conversion receiver of this kind was described by White in 1961.[2] However, this receiver used several tubes, including an r.f. amplifier, and was just about as complicated as a small superhet. By utilizing the high quality, inexpensive semiconductors currently available to the amateur, the basic performance of White's receiver is achieved with a much simpler circuit.



Complete receiver, as shown, is rather compact. The *antenna trimmer capacitor, C_1, is the control to the* lower left. The vernier dial is mounted directly on the front panel.

The unit built by the authors is shown schematically in Fig. 1. It operates in the 3.5-MHz. band. This receiver was designed for simplicity and ease of duplication rather than for ultimate performance. Nonetheless, this unit in many ways outperforms many of the less-expensive commercial receivers on the market today.

The antenna is coupled directly to the product detector through a single tuned circuit. With the component values shown, either the 3.5-MHz. or 7-MHz. band may be tuned. Following the input tuned circuit is the heart of the receiver, a product detector. It consists of four diodes operating in a ring configuration as a double balanced mixer. While typical junction diodes can be used in this circuit, the hot-carrier diodes[3] used by the authors are strongly

*Display Device Development, Tektronix, Inc., P.O. Box 500, Beaverton, Oregon 97005.

**9021 W. Shorewood Drive, Mercer Island, Washington 98040.

[1] Villard, "Selectivity in S.S.S.C. Reception," *QST*, April, 1948.

[2] White, "Balanced Detector in a T.R.F. Receiver," *QST*, May, 1961.

[3] Most semiconductor diodes in use today are p-n junction devices. Recent technological advances allow the economical fabrication of hot-carrier, or Schottky barrier diodes which are basically metal-semiconductor junctions. Practical advantages of hot-carrier diodes include low noise, fast switching speed and excellent uniformity. The Hewlett-Packard 5082-2800 recommended by the authors sells for $0.99 in unit quantities. They may be purchased from any H. P. sales office. To find the sales office nearest you, consult the white pages of your telephone directory, or send an s.a.s.e. to Mr. B. A. Coler, Regional Sales Manager, H. P. Associates, 620 Page Mill Road, Palo Alto, California, 94304, who will inform the builder of the closest H. P. sales office.

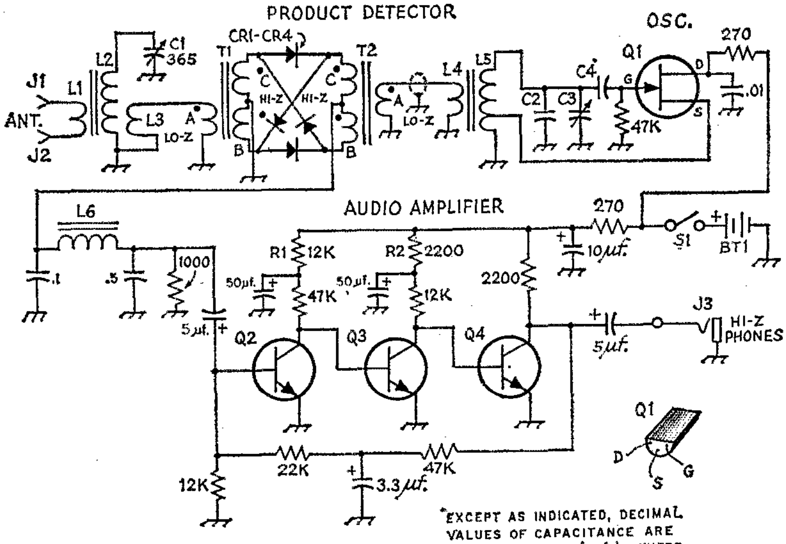


Fig. 1—Schematic diagram of direct conversion receiver. The 0.01-µf. capacitor is disk ceramic. The 0.1- and 0.5-µf. capacitors are paper or mylar. Polarized capacitors are 15-volt electrolytic. Fixed resistors are ½-watt carbon.

BT_1—9-volt transistor radio battery.
C_1—365-pf. variable (t.r.f. variety).
C_2—470-pf. silver mica for 3.5 MHz., 120-pf. silver mica for 7 MHz.
C_3—140-pf. variable for 3.5 MHz., 40-pf. variable for 7 MHz.
C_4—680-pf. silver mica.
CR_1-CR_4—See text footnote.
J_1, J_2—Insulated banana jacks.
J_3—Phone jack.
L_1, L_3—3-turn link, No. 28 enameled wire, wound on L_2.
L_2—40-turns, No. 28 enameled wire, wound on 0.680-inch diameter toroid.
L_4—5-turn link, No. 22 enameled wire, wound on L_5.
L_5—22-turns, No. 22 enameled wire, wound on 0.680-inch diameter toroid; tapped 5 turns from ground end.
L_6—88-mh. toroid.
Q_1—Motorola MPF-102.
Q_2, Q_3, Q_4—N-p-n, RCA 40233.
R_1, R_2—See text.
S_1—S.p.s.t. toggle.
T_1, T_2—See text.

recommended. The local oscillator consists of a simple Hartley circuit with link coupled output. For simplicity, no voltage regulation is used. The product detector provides a constant load to the oscillator, making a buffer stage unnecessary.

The output of the mixer is applied to a single-section low-pass filter using one of the common 88-mh. toroidal inductors. This filter is definitely needed in that it prevents mixer output signals beyond the audible audio frequency range from overloading the audio amplifier. It also defines the bandwidth of the receiver. The audio amplifier, although quite simple, provides over 100 db. gain. Indeed, it provides the gain for the entire receiver. It is quite important that high-beta, low-noise transistors be used. The devices specified are intended for hi-fi preamplifier applications, are quite inexpensive, and yield satisfactory performance. One will note that no audio gain control is included in the receiver. A strong c.w. signal will easily saturate the audio amplifier. However, the clipping is symmetrical and minimal distortion is introduced. With stronger s.s.b. signals, the gain may be reduced by slightly detuning the antenna trimmer capacitor.

Construction

The method of construction of the receiver is not critical with the exception that the local oscillator should be isolated from the rest of the circuitry and the high gain of the audio amplifier should be respected.

The receiver is built on a 5 × 7 × 2-inch aluminum chassis. A 6 × 5-inch piece of aluminum is used for the front panel. The authors used a 2⅞-inch diameter imported vernier dial although any suitable dial may be employed. The component layout used in the version shown in the photographs is conservative and should be generally followed. Considerable miniaturization is possible if the builder so desires.

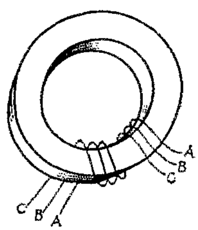
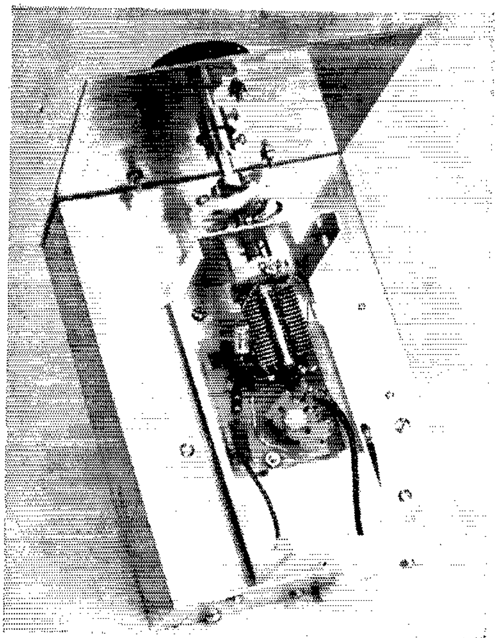


Fig. 2—Proper method of winding toroidal transformers, T_1 and T_2.



The oscillator components are mounted on a single circuit board. The FET is hidden below the tuning capacitor, C_3. Note that the output from L_4 is taken through a shielded cable. The insulated shaft coupling shown is a Johnson type 250.

The local oscillator should be isolated from the rest of the circuitry and for this reason it is housed in a 5 × 2¼ × 2¼-inch aluminum box mounted on top of the chassis.

The audio amplifier may be constructed on a perforated phenolic board or on a printed circuit board. The input and output should be physically separated to prevent undesired oscillation. High-impedance headphones (2000 ohms or more) should be used with the amplifier.

It would be wise to test the audio amplifier before mounting it in the chassis. A 9-volt battery and earphones should be connected to the finished circuit board. You should then hear a quiet hissing sound because of the noise generated in Q_2. If an audible oscillation occurs, it may be eliminated by increasing the value of the decoupling resistors, R_1 and R_2. If no noise output is heard, the amplifier may be oscillating at a frequency beyond the audio range (e.g., 100 kHz.). This oscillation is usually eliminated by placing a 0.01-μf. disk capacitor across the amplifier output or by again increasing R_1 and R_2. When mounting the amplifier in the chassis, the low-pass filter elements should be located away from the amplifier's output.

The transformers T_1 and T_2 are easily fabricated on small toroidal coil forms[4] with reference to the sketch in Fig. 2. Three pieces of No. 28 enameled wire are held together and wound trifilarly on each toroid. Fifteen turns are adequate. After winding, the leads are trimmed to about an inch in length and the enamel is removed. Then, using an ohmmeter, the beginning and end of each of the three windings is identified (A, B, C). Winding A is used as the low impedance winding. The beginning of winding B is connected to the end of winding C, providing the center tap for the bifilar high-impedance winding.

Performance

The performance of this receiver is surprisingly good. Sensitivity is adequate and c.w. signals of less than a microvolt may be copied. Stability is superb. The bandwidth is a little broad, but entirely adequate for casual work on the 3.5-MHz. band. Several 3.5-MHz. Asian

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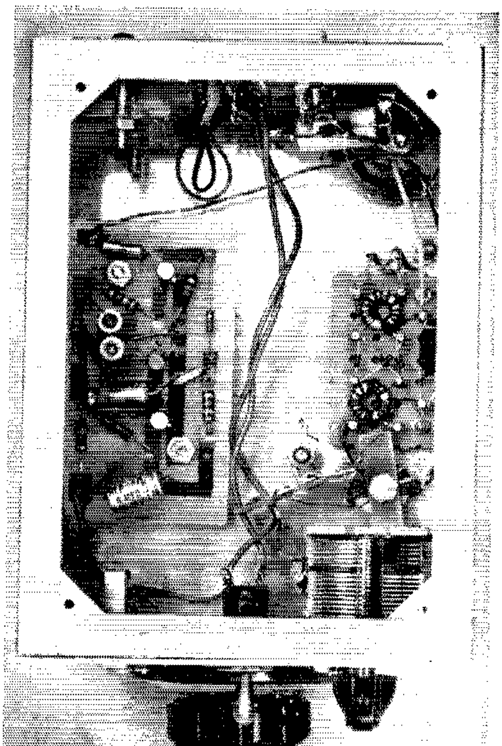
[4] Approximately 7/16-inch diameter. A kit of two suitable toroids is available for $1.00, postpaid, from Alcom Electronics, 2025 Middlefield Road, Mountain View, California, 94040.



The underside view of the receiver reveals a rather uncluttered appearance. The product detector and associated transformers, T_1 and T_2, are mounted on a small piece of prepunched terminal board which is located in the right, center of the chassis. L_6 is mounted in the right rear of the chassis. The audio amplifier is mounted on a printed circuit board to the left. The battery is fastened to the rear wall of the chassis using two machine screws and a plastic plate.

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stations were logged with this receiver in the 1968 ARRL DX Test. The cross-modulation performance is at least equivalent to that of a medium-priced superhet and certainly much better than that of a regenerative receiver.

Additional Thoughts

The receiver is easily adapted to other bands by changing the input tuned circuit and the local-oscillator frequency. Oscillator coil data for 7-MHz. operation is included in Fig. 1. The more experienced experimenter may build the receiver for other bands by using the oscillator from the HBR-TR [5], with changes in the inductance values. Alternatively, it would be possible to make a stable master oscillator on 3.5 MHz. and construct a multiplier chain to derive local-oscillator injection for the higher bands. The product detector performs adequately with a local-oscillator injection level of 0.6 volt peak to peak. Measurements have shown the receiver's usable sensitivity to be constant at less than a microvolt over the range of 3.5 to 50 MHz., the limit of the test equipment used for the measurements. The manufacturer's data for the hot-carrier diodes suggests that the principles are easily adaptable to the 144-MHz. band, and perhaps even higher in frequency.

One disadvantage of the direct conversion approach is the ever-present audio image. While phasing techniques could be applied, the complexity of such a receiver would make a superhet more practical.

Since the local oscillator of a direct conversion receiver operates at essentially the same frequency as the received signal, the addition of an r.f. power amplifier would yield a very simple transceiver. Careful buffering of the v.f.o. is of course required. A unit in frequent use at W7WKR is such a transceiver. The rig operates on the 3.5-MHz. c.w. band, and is completely contained in a 3 × 4 × 5-inch box. With an output power of a tenth of a watt, hundreds of contacts have been made.

Clearly, the addition of switching at the input and output of the product detector would allow it to function as a balanced modulator for the generation of a double-sideband, suppressed-carrier signal. This could be the basis for a very simple phone transceiver for modern "hill topping."

While certainly not providing the ultimate in performance, the unit described represents perhaps the simplest approach to the construction of a truly usable receiver.

The authors gratefully acknowledge the ideas and comments of W7ZHA and W7DRA. Special thanks go to Chuck Wilcox, K6DMW, who contributed to many of the earlier experiments. QST

[5] Daughters, Hayward, and Alexander, "Solid State Receiver Design using the MOS Transistor, Part I," *QST*, April, 1967.