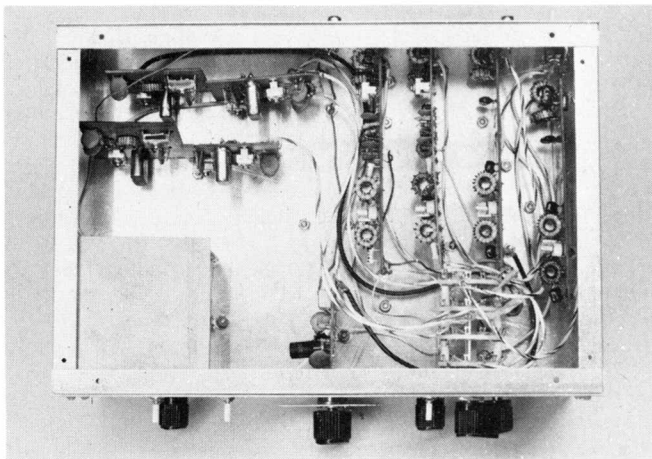


A High-Performance Communications Receiver

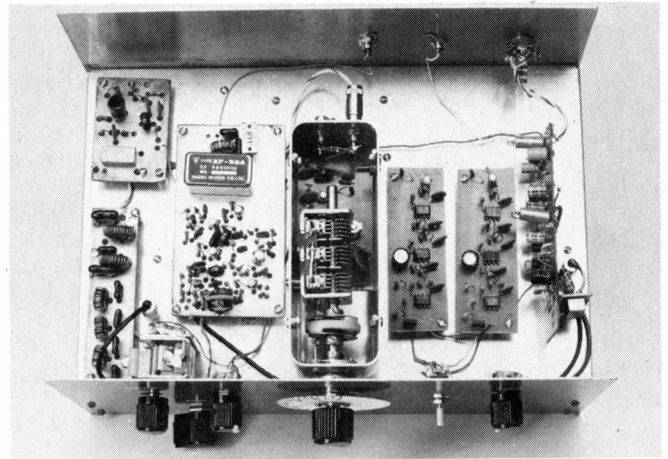
The receiver described here is the work of W7ZOI and K5IRK, and was presented in November 1981 *QST*. A progressive

system was used in the *QST* version, starting with a simple (but very useable) direct conversion receiver and concluding with a

multiband superheterodyne. This approach is highly recommended for those who may lack construction experience.



(A)



(B)

Fig. 10 — A 5-band, SSB version of the high-performance communications receiver constructed by K5IRK. In the top view, the VFO is located in the center with the input filter, mixer and IF boards to the left. The board at the far right contains the product detector and audio stages. The two boards to the right of the VFO are active audio filters (A). The bottom view shows the converter and oscillator boards. The BFO is contained in the shielded box at the left and the mixer board is at the lower center (B).

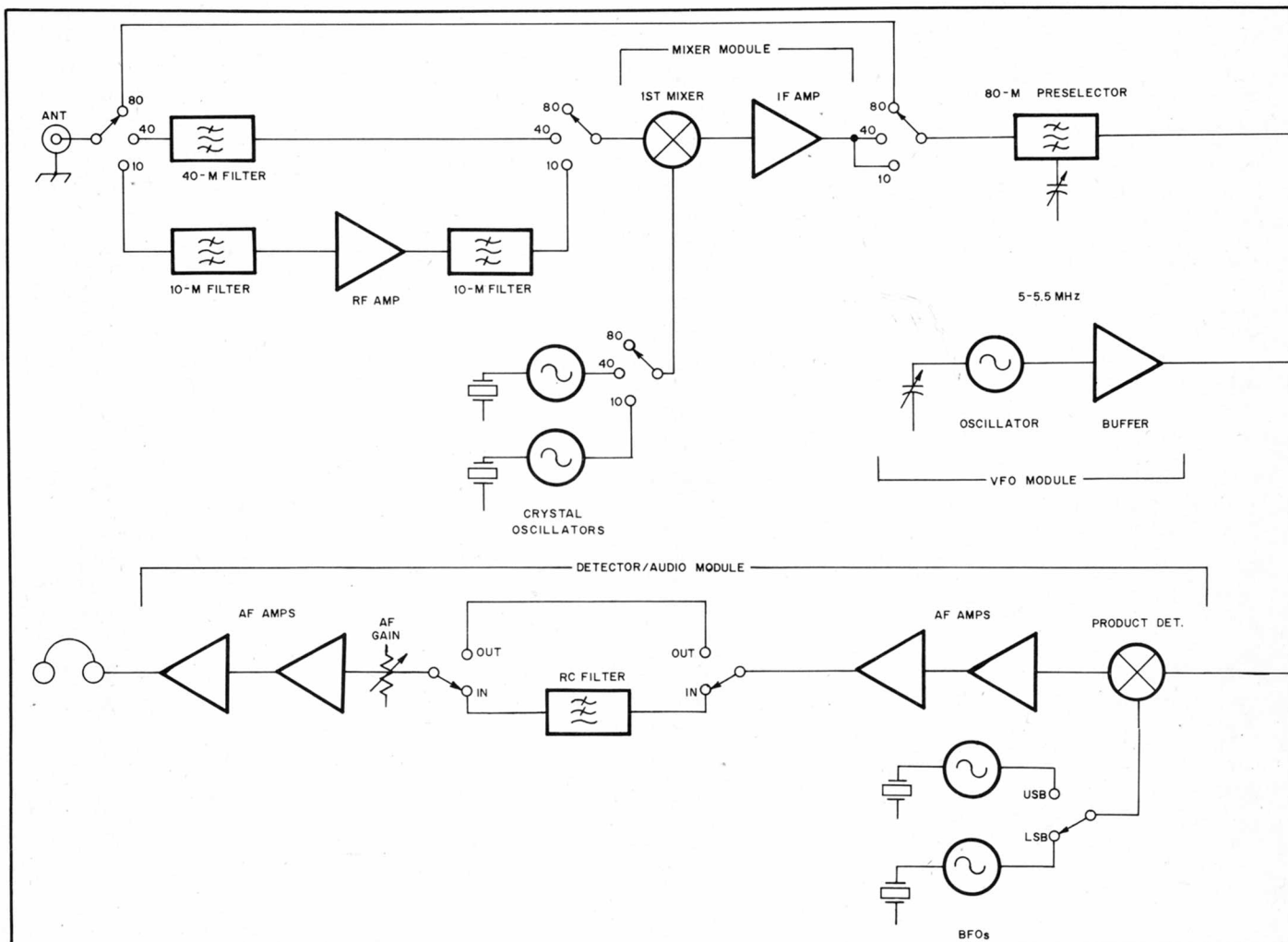


Fig. 11 — Block diagram of the W7ZOI/K5IRK communications receiver.

Shown in Figs. 10 through 19 is the receiver in its final form. The overall layout is shown in the block diagram, Fig. 11. On 80 meters the receiver functions as a single-conversion superheterodyne, with reception of the higher bands provided by higher-performance crystal-controlled converters. All of the converters use the same mixer module, switching only the converter filter and crystal oscillator modules. As shown, the 40-meter converter does not use an RF amplifier — it is unnecessary and it degrades dynamic range. The lower noise figure obtained with the RF stage is required on the bands above 7 MHz, however.

Many criteria were used in the design of this receiving system, but first and foremost were simplicity and ease of duplication. To this end, readily available components were used throughout. Alternative components are suggested where appropriate, and the circuits are insensitive to transistor type, allowing freedom in substitution. This does not in any way imply that the performance has been compromised; indeed, this receiver can equal the strong-signal performance of many of the high-priced receivers

on the market today.

Circuit Description: The Converter, Filter and RF Amplifier

Preselection for the individual converter sections is provided by the circuit shown in Fig. 12. The optional RF amplifier is shown in A, and the version without the amplifier is shown in B. The same circuit board layout can be used for both versions.

Each filter module uses two types of filters. The first is a 5-pole low-pass, necessary to prevent spurious responses from VHF TV and FM broadcast signals. The second filter provides the majority of the front-end selectivity. It is a double-tuned circuit comprised of L7, L8 and their related capacitors. A variable capacitor is used at C15 because the small, non-standard values required here are difficult to obtain; a 1- to 5-pF variable is readily available and can be preset to the value given in Table 1 or adjusted during alignment.

The RF amplifier uses a dual gate MOSFET and modified-input low-pass filter. The first section is a simple low-pass filter, while the second section is a pi net-

work that transforms from 50 to 2000 ohms with a Q of 10. This provides an optimum driving impedance for the amplifier. The output uses a broadband transformer to provide a 50-ohm output impedance, ensuring proper termination for the following double-tuned circuit.

The filters may be aligned with a signal generator or crystal calibrator. If a calibrator is used, the input of the receiver should be terminated with a 50-ohm resistor. Initially, C15 is set near minimum capacitance, and the receiver is tuned to the center of the band. C14 and C17 are then adjusted for maximum response. C15 is then partially meshed, and C14 and C17 are again peaked for maximum response. The filter bandwidth is estimated by observing the response as the receiver is tuned toward band edges. This procedure is repeated until the desired bandwidth is realized. The input pi network used with the RF amplifier is adjusted by setting C22 for maximum response at the center of the band.

Mixer Module

The two mixer modules used in the composite receiver are identical, each being comprised of a doubly balanced diode-ring mixer, U2 of Fig. 13, followed by a 9-MHz IF amplifier, Q9, is one of the more critical stages in the receiver. It must have a reasonable noise figure, low IMD, and a 50-ohm input and output impedance. A bipolar transistor with negative feedback is used to establish the gain and impedances. The 6-dB pad at the output preserves the input and output match of the stage. The moderately high bias current used ensures low distortion.

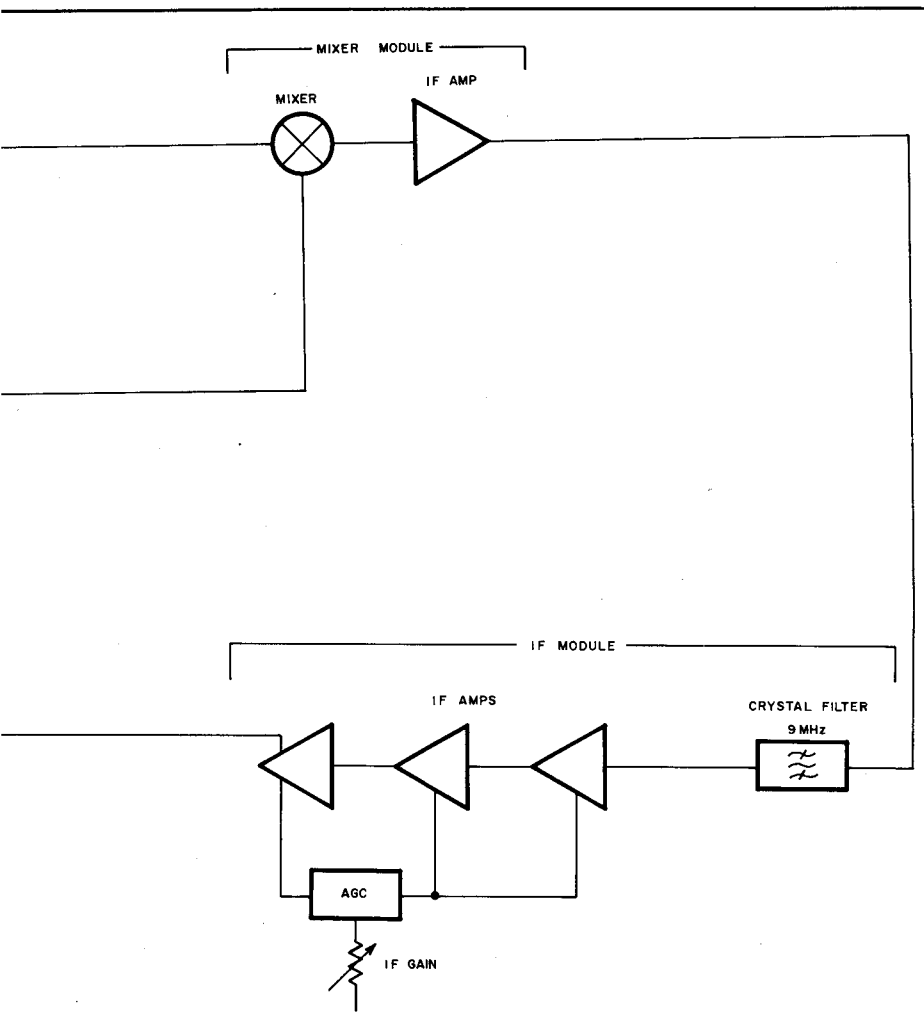
The transistor type used for Q9 is critical. It should have an F_t of at least 500 MHz. The 2N5109, 2N3866 and 2SC1252 are all suitable.

Amplifier gain, including the loss of the pad, is about 16 dB. The mixer has a loss of about 6 dB, leaving a net module gain of 10 dB. The amplifier output intercept is about +30 dBm. Careful measurements have shown that a diplexer is not required between the mixer and the amplifier.

Crystal Oscillator Module

Shown in Fig. 14 is the circuit used for all of the crystal oscillators in the receiver. One or two of the modules are used for the BFO, and one module is used with each converter. The circuit is a Hartley oscillator with the crystal in series with the feedback tap from the coil. A trimmer capacitor in series with the crystal adjusts the operating frequency of the oscillator. If a single BFO is used, the 12-volt operating bias is applied through the output link as shown in Fig. 14B. When more than one module is used, as with the converters, operating voltage is applied through the bandswitch, Fig. 14C. Only the oscillator in use has power applied to it.

This circuit will deliver an output power



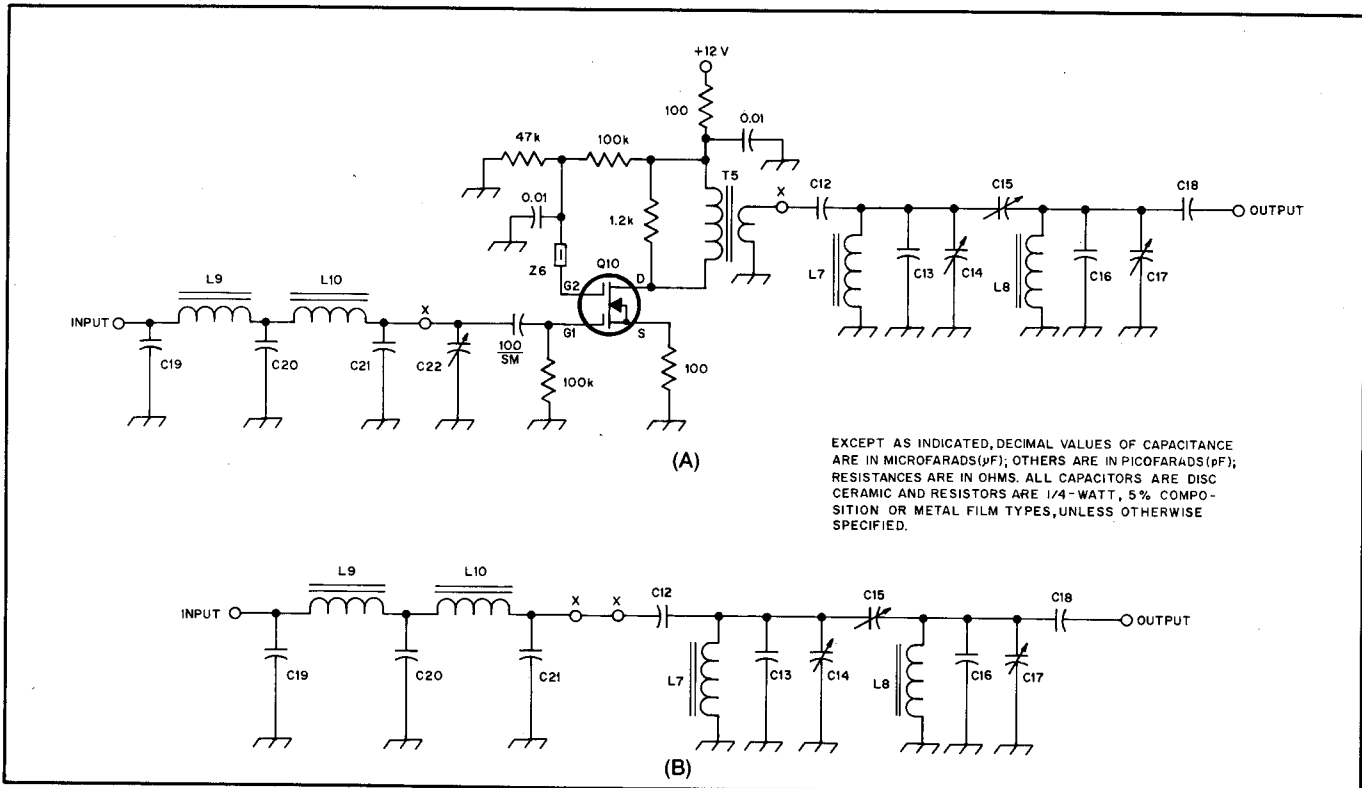


Fig. 12 — Circuit diagram of the converter filter and optional RF amplifier used in the W7ZOI/K5IRK receiver. The circuit using the RF amplifier is shown in A, while the configuration without the amplifier is shown in B.

C12, C13, C16, C18-21 — Silver mica or ceramic, see Table 1 for values.
 C14, C17, C22 — Mica compression trimmer or similar variable, see Table 1 for values.
 C15 — Air variable, 1 to 5 pF.

L7-10 — No. 22 enamel wire wound on Amidon T50-6 core, see Table 1 for number of turns.

Q10 — Dual gate MOSFET, 40673, 3N211,

3SK40 or similar.

T5 — Ferrite transformer, 20 turns primary, 4 turns secondary, on Amidon FT37-43 core.
 Z6 — Ferrite bead on lead of Q10. Amidon type FB43-101.

of about +10 dBm, which is more than enough to drive the diode mixers. Adjustment of the oscillators should be done with the mixer attached. C11 is tuned for maximum output and proper starting of the oscillator. The series capacitor is then adjusted for the correct operating frequency. This capacitor may be eliminated in those modules used with the converters. In these cases, the crystal is connected directly to ground.

80-Meter Preselector Filter

The 80-meter preselector filter is shown in Fig. 15. It consists of two cascaded filters: The first is a 7-pole, high-pass (3-MHz cutoff), composed of the components between the two 650-pF capacitors. This filter suppresses spurious responses from AM broadcast signals. The second part of the filter, while basically a low-pass type, was designed for a very pronounced peak, resulting in a sharp, bandpass-like response. C6 is a 365-pF broadcast capacitor mounted on the front panel.

VFO Module

The variable frequency oscillator, Fig. 16, uses a JFET in a Hartley circuit, followed by a dual-gate MOSFET buffer. For best temperature stability, type SF material (Amidon -6 code) is used for the inductor

Table 1

Component Data for W7ZOI/K5IRK Receiver Converter Filters

Parts for filter without amplifier:

F, MHz	C19	C20	L9 L10	C12 C18	C13 C16	C14 C17	C15	L7 L8
7.1	430	860	17	42	50	180	4.6	25
10.6	300	600	13	32	50	180	4.1	17
14.2	220	430	12	20	—	180	2.3	17
18.2	180	360	10	22	50	180	3.9	10
21.2	150	300	10	18	—	180	3.0	10
24.2	130	270	9	14	—	180	2.1	10
28.5	110	220	8	12	—	180	1.6	10

Parts for filter with RF amplifier:

F, MHz	C19	C20	C21	C22	L9	L10
10.6	300	680	33	50	13	29
14.2	220	500	22	50	12	25
18.2	180	390	—	50	10	22
21.2	150	330	—	50	10	20
24.2	130	300	—	50	9	19
28.5	110	250	—	50	8	17

Note: Other filter parts are identical to that without the amplifier. Values listed for capacitors are capacitance in pF. Values listed for inductors are the number of turns of wire required.

core, as this material has a lower temperature coefficient than the usual slug-tuned inductor. All of the capacitors in the tuned circuit should be NP0 ceramics, as they have the lowest temperature coefficient of any readily available type. Silver mica and polystyrene types should not be used in this circuit.

The resonator (tuned circuit) should be

lightly loaded; to this end, the coupling capacitor to the gate of the JFET is kept as small as possible. If the specified 2.7-pF NP0 ceramic cannot be obtained, a small air variable of similar value can be substituted. Following these precautions will ensure excellent stability. Typical warm-up drift is under 200 Hz over a period of 10 minutes. After warm-up, drift

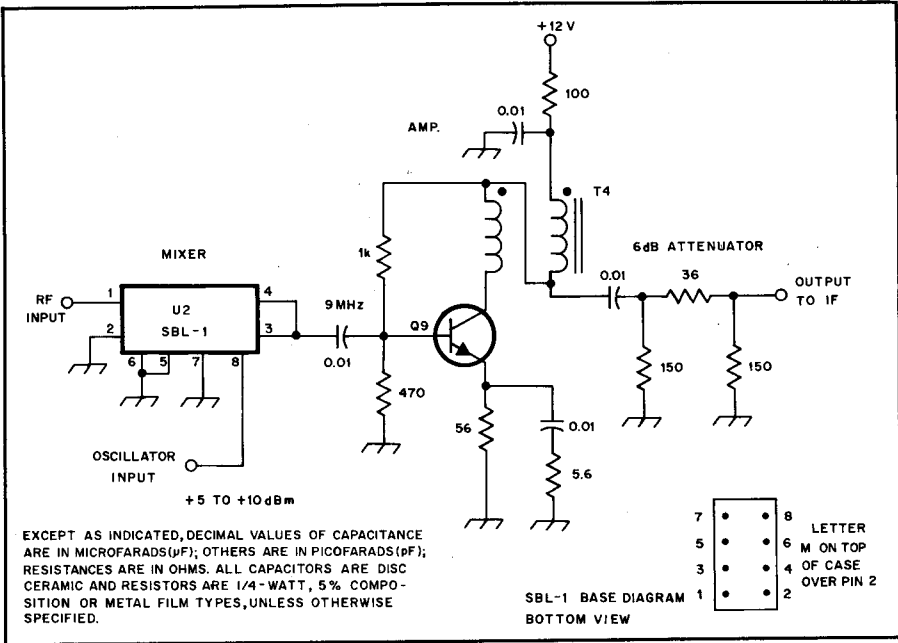


Fig. 13 — Diagram of the mixer module. Two of these modules are used in the completed receiver. One is for 80-meter input, with its output at 9 MHz. The second is used with the converters; its output is at 80 meters.

- Q9 — TO-39 CATV type bipolar transistor, $F_T = 1$ GHz or greater, 2N5109, 2SC1252 2SC1365 or 2N3866 suitable. A small heat sink is used on this transistor.
- T4 — Broadband ferrite transformer, 10 bifilar turns no. 28 enamel on Amidon FT37-43

- core.
- U2 — Mini Circuits Lab doubly balanced mixer, type SBL-1. Type SRA-1 is also suitable, as are similar units from other manufacturers.

is no more than 10 or 20 Hz in a 5-minute period.

The buffer stage, Q7, is conventional with the exception of the broadband output transformer, T2. The buffer provides good isolation for the oscillator and an output power of between +5 and +8 dBm.

Intermediate Frequency Amplifier

The heart of this receiver is its IF section. This design uses an IF of 9 MHz, with selectivity provided by a crystal filter of the builder's choice. The circuitry shown in Fig. 17 is designed for a filter requiring 500-ohm input and output terminations.

The input is a pi network which transforms the 50-ohm source impedance of the mixer module to the 500 ohms required by the filter. The filter output is terminated in a 560-ohm resistor.

The majority of the IF gain is provided by two dual-gate MOSFETs, Q11 and Q12. The bias on these stages is shifted upward by a pair of silicon diodes. This extends the gain control range as the gate 2 bias is altered. The last IF stage is a differential pair of PNP transistors, Q13 and Q14. Outputs are available from each of the collectors. The one from Q14 is routed through coaxial cable to the product detector.

The other IF output drives the detector,

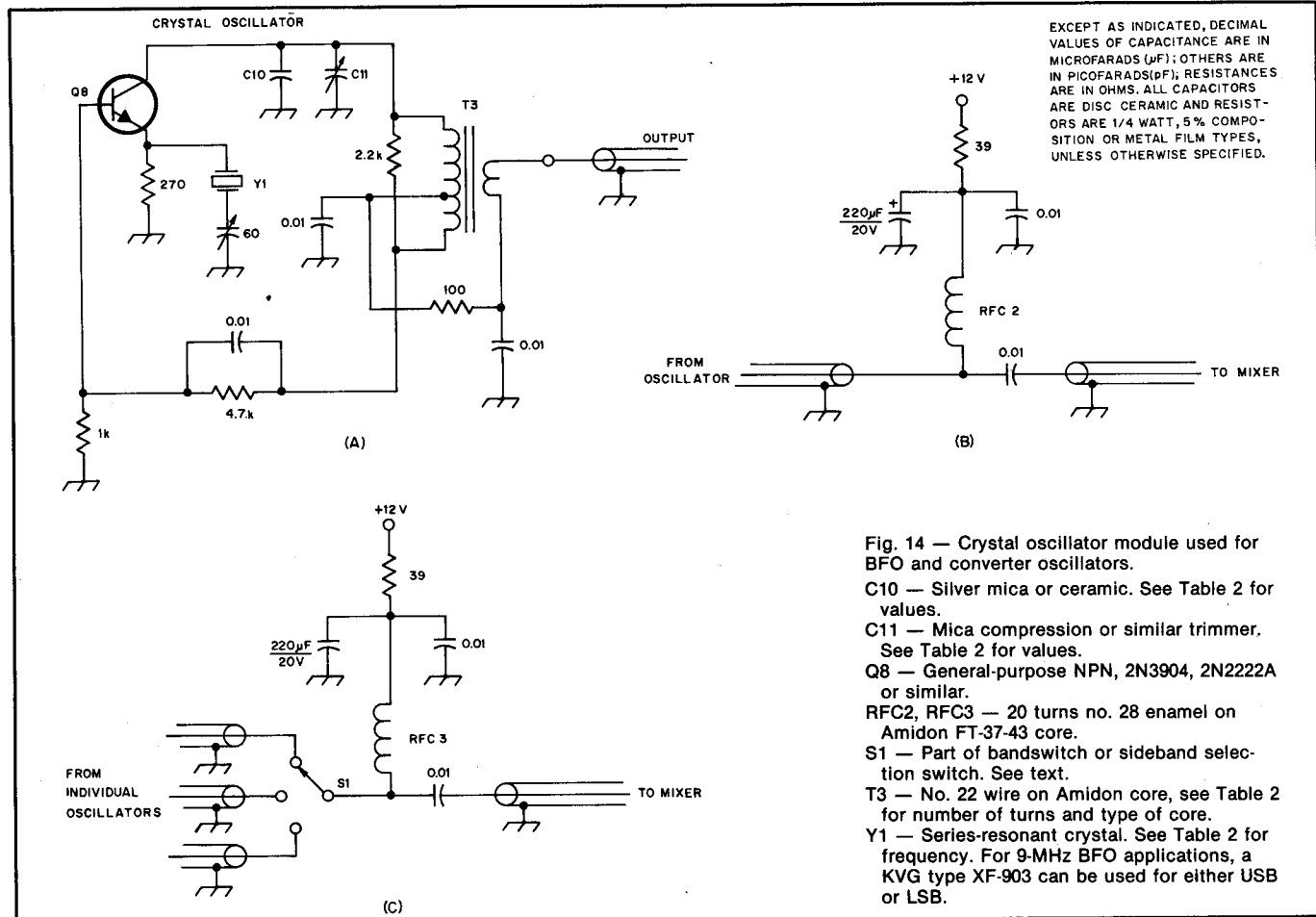


Fig. 14 — Crystal oscillator module used for BFO and converter oscillators.

- C10 — Silver mica or ceramic. See Table 2 for values.
- C11 — Mica compression or similar trimmer. See Table 2 for values.
- Q8 — General-purpose NPN, 2N3904, 2N2222A or similar.
- RFC2, RFC3 — 20 turns no. 28 enamel on Amidon FT-37-43 core.
- S1 — Part of bandswitch or sideband selection switch. See text.
- T3 — No. 22 wire on Amidon core, see Table 2 for number of turns and type of core.
- Y1 — Series-resonant crystal. See Table 2 for frequency. For 9-MHz BFO applications, a KVG type XF-903 can be used for either USB or LSB.

D1. When large signals are present, the detected voltage from D1 appears at the base of Q16, discharging the timing capacitor, C24. The voltage change at C24 is coupled to the line through a diode, and reduces the gain of Q11 and Q12. R10, the "AGC set," is adjusted for a dc potential of 0.4- to 0.5-volt at the base of Q16. This adjustment is made with the AGC on, with no signals present. When measured with a high-impedance voltmeter, the AGC line should show about 6 volts at maximum gain.

Two transistor switches are contained in the amplifier. Q17 is used to defeat the

Table 2

Component Data for W7ZOI/K5IRK Receiver Crystal Oscillator Module

Y1	Band	C10	C11	Core type	T3 primary turns	tap turns	secondary turns
3.3 MHz	40	100 pF	90 pF	T68-2	65	13	10
9	BFO	56	60	T50-6	35	7	6
10.5	20	56	60	T50-6	30	7	6
11	20/40	22	60	T50-6	30	7	6
17.5	15	33	60	T50-6	23	5	4
24.5	10/15	—	60	T50-6	20	4	4
32	10	—	60	T50-6	15	3	3
6.5	30	100	60	T50-6	35	7	6
14.5	17	33	60	T50-6	23	5	4
20.5	12	—	60	T50-6	20	4	4

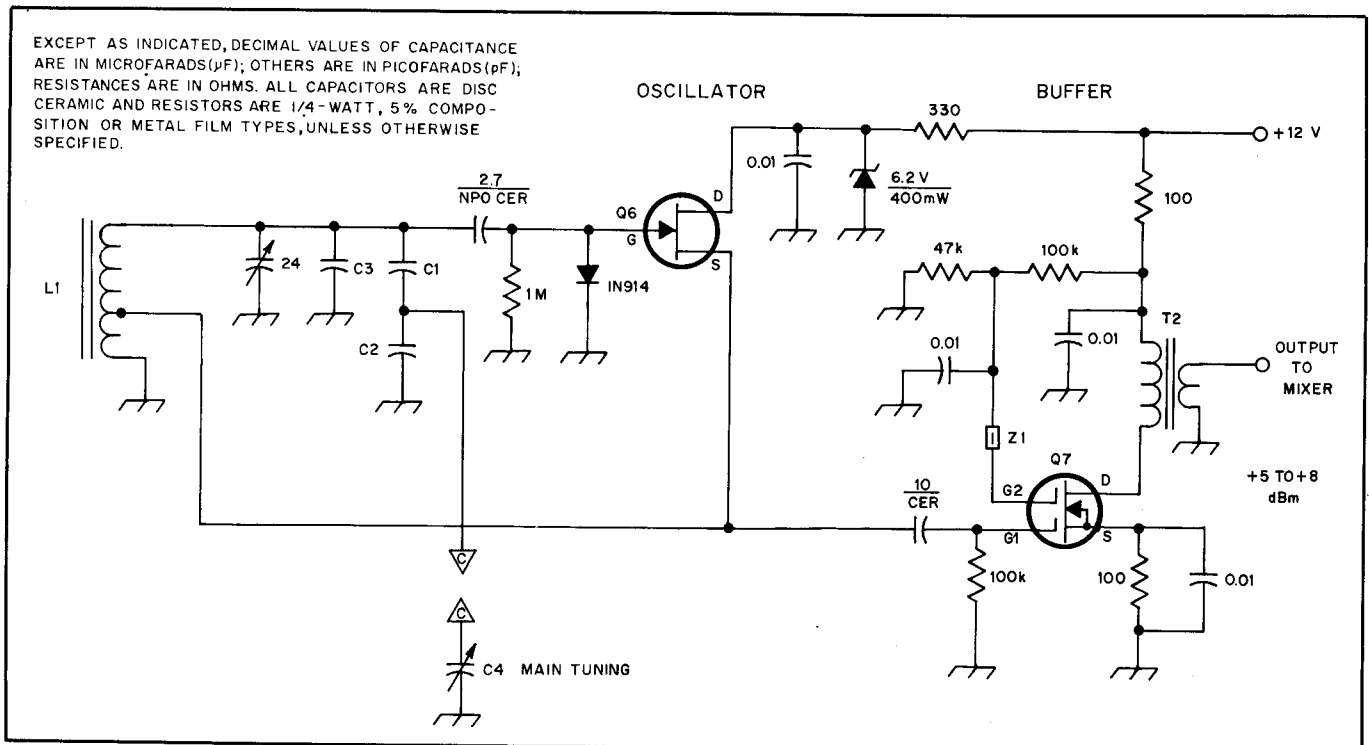
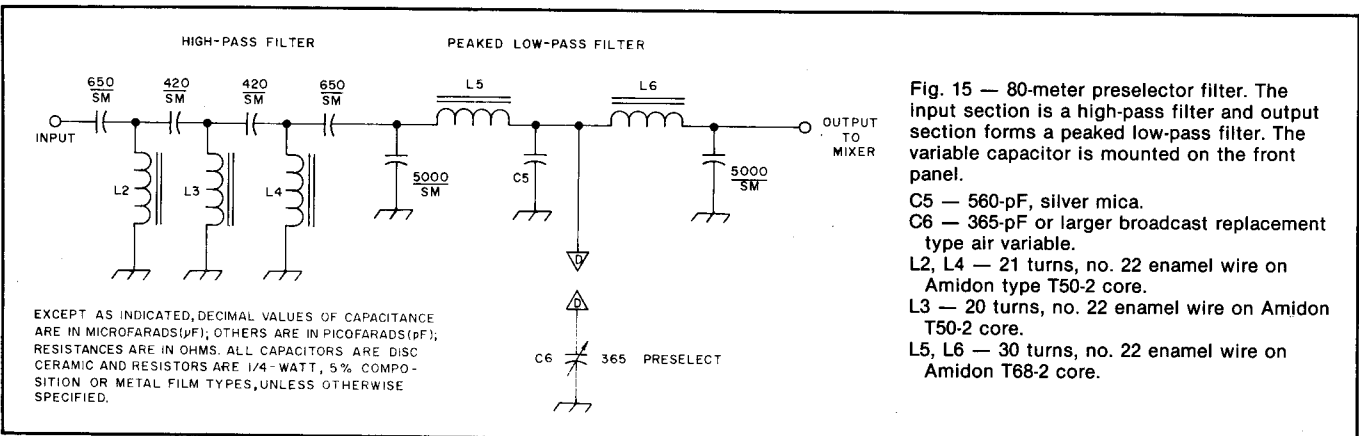


Fig. 16 — Schematic diagram of the VFO used in the W7ZOI/K5IRK receiver. This circuit will function well from 2.5 to 10 MHz. The tuning range using the components listed is 5.0 to 5.5 MHz.

- C1 — 100-pF NPO ceramic.
- C2 — 82-pF NPO ceramic.
- C3 — 126-pF NPO ceramic.
- C4 — Air variable, 365-pF broadcast replacement type.
- L1 — 35 turns no. 28 enamel wire on Amidon

- T50-6 core. Tap 8 turns from ground. Approximately 4.9-μH total inductance.
- Q6 — General-purpose JFET, MPF-102, 2N4416 TIS-88, 2SK19GR or similar.
- Q7 — Dual gate MOSFET, 40673, 3N140, 3N211, 3SK40 or similar.

- T2 — Ferrite transformer, 18-turn primary, 5-turn secondary, no. 28 enamel wire on Amidon FT37-43 core.
- Z1 — Ferrite bead on lead of Q7. Amidon FB43-101 or similar.

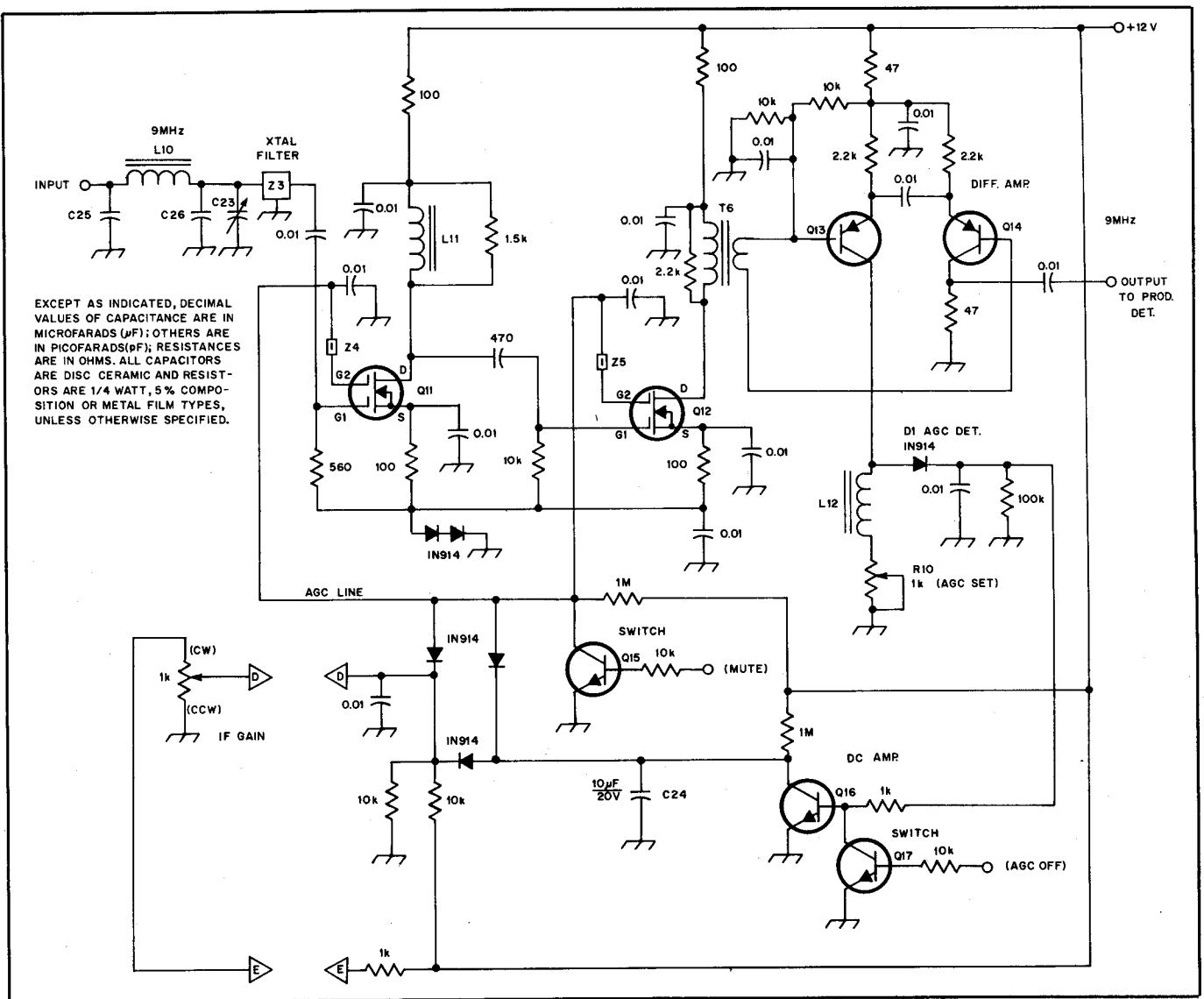


Fig. 17 — Schematic diagram of the 9-MHz IF amplifier.

C23 — 90-pF compression trimmer or similar variable.
 C25 — 470-pF silver mica or ceramic.
 C26 — 130-pF silver mica or ceramic.
 L10 — 23 turns, no. 22 enamel wire on Amidon T50-6 core.
 L11, L12 — 15 turns, no. 22 enamel wire on Amidon FT37-43 core.
 Q11, Q12 — Dual-gate MOSFET, 40673,

3N140, 3N211, 3SK40 or similar.
 Q13, Q14 — PNP silicon transistor, 2N2907A, 2N3906, 2N4403 or similar.
 Q15-17 — NPN silicon transistor, 2N2222A, 2N3904, 2N4401 or similar.
 R10 — 1-k Ω PC-board mount variable resistor linear taper.
 T6 — Ferrite transformer, 15-turn primary,

3-turn secondary, no. 28 enamel wire on Amidon FT37-43 core.
 Z3 — 9-MHz crystal filter, 500 ohm impedance level: For SSB, KVG type XF-9B, Yaesu XF-92A or Fox-Tango Corp., eq. For CW, KVG type XF-9M or XF-9NB, Yaesu XF-90C or Fox-Tango Corp., eq.
 Z4, Z5 — Ferrite bead on lead of MOSFET, Amidon FB43-101 or similar.

AGC. It is activated by a positive voltage applied to the "AGC off" line. The other switch, Q15, is attached directly to the AGC line. A positive voltage applied to its input shorts the AGC line to ground, muting the receiver. The extra diodes allow muting to occur quickly while not discharging C24. The IF returns rapidly to full gain after muting periods.

The AGC response is more than adequate and overshoot is minimal. Recovery time is relatively independent of signal level. The recovery time may be shortened by decreasing the value of C24 or the associated 1-megohm resistor.

Detector Audio Module

The IF section of the receiver is followed

by the detector and audio amplifiers, shown in Fig. 18. The detector used here is a doubly balanced diode-ring mixer, a Mini-Circuits Labs SBL-1. Mixers from other manufacturers or homemade equivalents will work as well. The excellent balance provided by this type of mixer helps eliminate problems with the AGC system caused by BFO leakage.

The detector output is applied to a diplexer network formed by RFC1 and related components. This network ensures that the detector is properly terminated at all frequencies from audio to VHF.

The first audio amplifier is somewhat unusual in that it uses the common-base configuration. When biased for an emitter current of about 0.5 mA, it provides the

50-ohm input impedance necessary to properly terminate the detector. The second audio stage, Q2, is a direct-coupled PNP amplifier. The receiver may be muted by shorting the collector of Q2 to ground. This is done by applying a positive voltage to the muting input, saturating Q5. The output of Q2 drives the audio gain control, which is mounted on the front panel. If the optional RC active filter is used, it is connected between the output of Q2 and the gain control.

Q3 functions as a common-emitter amplifier, while Q4 is an emitter follower. Q4, biased for an emitter current of about 30 mA, provides sufficient audio output to drive low-impedance (4 to 16 ohms) headphones. If high-impedance headphones are

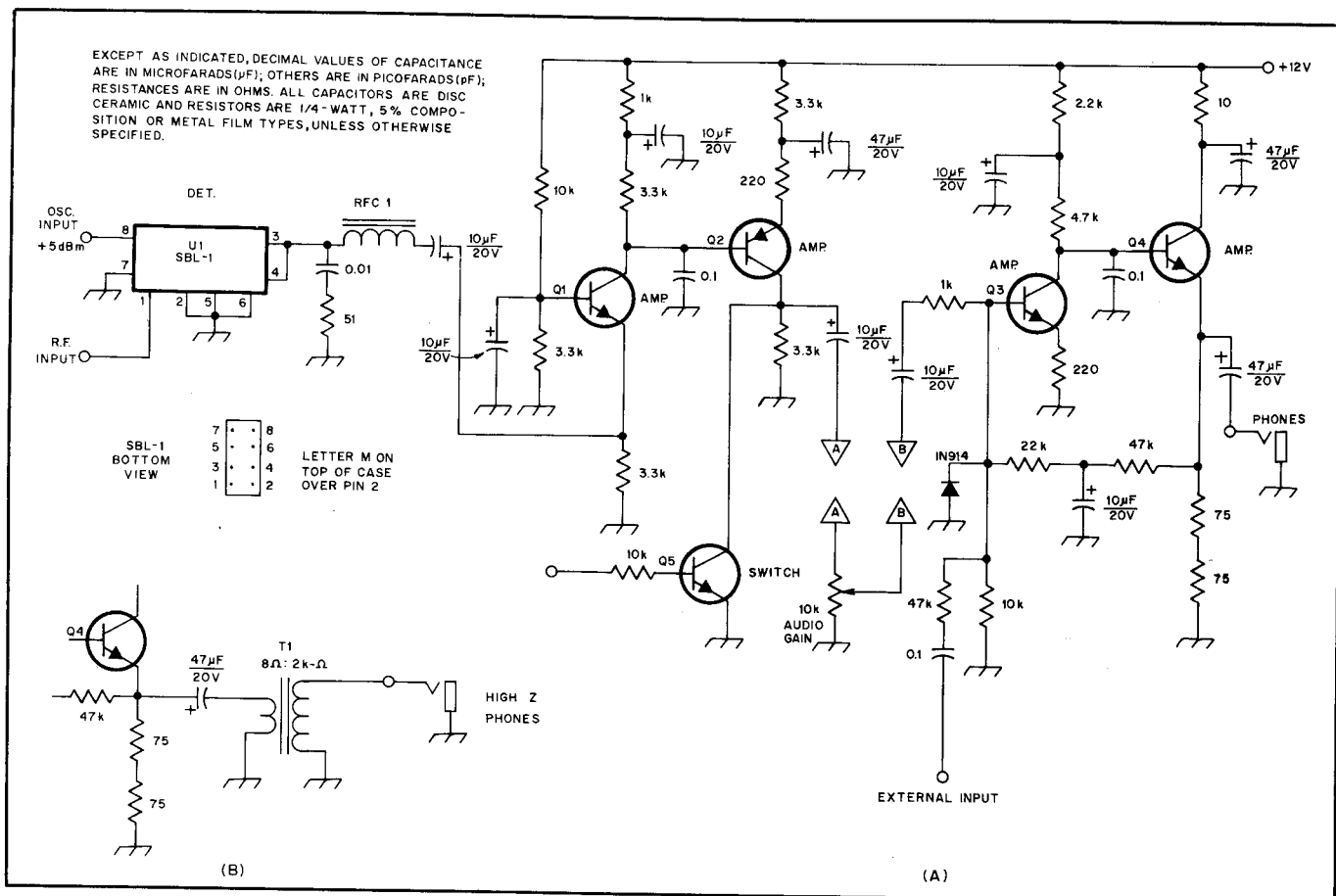


Fig. 18 — Schematic diagram of the product detector and audio amplifier. If high-impedance headphones are to be used, the output circuit shown in B is recommended.

Q1, Q3 — Low-noise NPN, 2N3565 or similar.
Q2 — General-purpose PNP, 2N3906 or similar.

Q4 — TO-5 or TO-39 NPN, 2N3053 or similar with small heat sink.
R3 — 10-k Ω audio taper.

RFC1 — 20 turns no. 28 enamel wire on Amidon FT37-43 ferrite toroidal core.

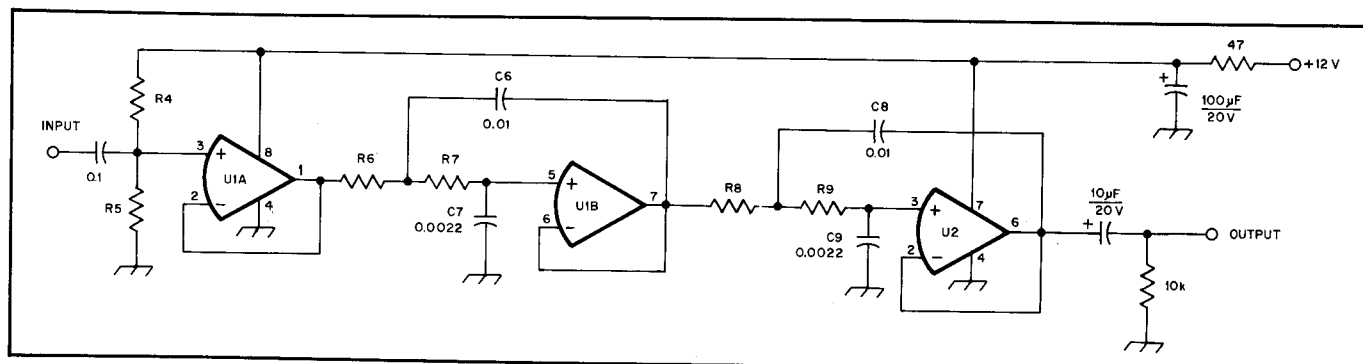


Fig. 19 — Schematic diagram of the optional RC active audio filter. A 4-pole low-pass filter is shown here. Additional sections may be added for improved performance.

C6, C8 — 0.01- μF , 10% or better tolerance, ceramic or polystyrene.

C7, C9 — 0.0022- μF , 10% or better tolerance, ceramic or polystyrene.
R4-9 — 33-k Ω for CW or 15-k Ω for SSB filter.

U1 — 1458 or similar, dual op-amp.
U2 — 741, or similar, op-amp.

to be used, a step-up transformer should be used to increase the system voltage gain. This is shown in Fig. 18B. An auxiliary input to the audio amplifier is provided for injection of a sidetone signal for CW monitoring.

The optional RC active filter shown in Fig. 19 can be used to improve selectivity during CW reception, especially when the

IF filter is of bandwidth suitable for SSB operation. As shown in Fig. 19, the filter has a single pole of high-pass filtering and four poles of low-pass response. The cutoff frequency is about 1-kHz for CW or 2-kHz for SSB. The filter bandwidth is determined through proper choice of resistor values. Values for both bandwidths are given in Fig. 19. The filter may be expanded to

many more sections for improved skirt selectivity.

Construction

Mechanical details, such as the type of cabinet and dial drive, are left to the discretion of the builder. Band switching is not critical, as all of the switched points occur at low impedance levels. A multi-wafer

Table 3
Measured and Calculated Receiver Performance Characteristics

Circuit	RF Amp.	Bandwidth, Hz	NF, dB	IP_{1m} , dBm	MDS, dBm	DR, dB
Single Conv.*	no	500	16	+ 18	- 131	99
Single Conv.	no	2500	16	+ 18	- 124	94
Single Conv.	yes	500	5	+ 2	- 142	96
Single Conv.	yes	2500	5	+ 2	- 135	92
Dual Conv.	no	500	18	+ 12	- 129	94
Dual Conv.*	no	2500	18	+ 12	- 122	89
Dual Conv.	yes	500	6	- 2	- 141	92
Dual Conv.*	yes	2500	6	- 2	- 141	88

RF amplifier assumed to have a 3 dB noise figure, a 15 dB gain and a +22 dBm output intercept. Circuits marked with (*) are measured cases. All measurements done at 14 MHz.

rotary switch will work well. Small coaxial cable, such as RG-174/U, should be used for all signal lines.

The version shown here was built by K5IRK. The bulk of the 80-meter part of the receiver is mounted above the chassis. The VFO is contained in an aluminum box, providing both shielding and mechanical strength. The BFOs are below the chassis in a box constructed of scrap circuit-board material. The converters are mounted below the chassis.

Homemade, etched circuit boards were used in the K5IRK model, while "ugly-but-quick" breadboards were utilized by W7ZOI in the construction of his receiver.^{1,2} "Ugly boards" are easily built, with scraps of unetched circuit-board material serving as ground foil. The circuitry is supported by those components that are normally grounded. Additional

support is provided by suitable tie points. Large-value resistors serve well for this purpose, especially in RF circuits where the impedance level is low. All of the circuitry for the receiver was initially breadboarded using this method. While not as "professional" in appearance, the performance was identical to that of later circuit board versions. In few cases where a performance difference could be detected, the ugly breadboards were superior, usually a result of improved grounding.

Performance

It should be emphasized that, although relatively simple, this receiver is not a toy. It features excellent stability, selectivity consistent with the filter used by the builder, adequate sensitivity, and a dynamic range that rivals or exceeds that of many commercially available equivalents. The only major compromise is the utilization of dual conversion on the higher bands. The penalty is small, because the gain distribution has been carefully planned.

System measurements were made on the receiver at various stages of development.

This data is summarized in Table 3. Both measured data and calculated results are presented to give the prospective builder some feel for the performance to be expected. The table shows the system noise figure, input intercept, minimum detectable signal and the two-tone dynamic range. Both CW and SSB bandwidths are considered in both single- and dual-conversion designs, with and without an RF amplifier. Measurements and calculations generally agree within 1 dB.

Table 3 reveals no surprises. The nature of the trade-off between single and dual conversion is well illustrated, as is the effect of adding an RF amplifier. The system showing the largest dynamic range is the single-conversion design without an RF amplifier. It should be noted that this data pertains only to the modules described. Changes in gain, noise figure or intercept of any stage will change the results. The table should not be used for general comparisons.

The dual-conversion systems are about 5 dB "weaker" than the single conversion ones; this is typical. It should be understood that this observation applies only to dual-conversion systems with a wide bandwidth first IF. Modern systems using a crystal filter at the first IF will display performance much the same as a single-conversion receiver, even if they utilize several conversions. No gain compression was measureable in the single-conversion model with no RF amplifier, even with an input signal of -10 dBm. VFO phase noise was measured to be -152 dBc/Hz at a spacing of 10 kHz.

Operationally, the receiver is pleasing to use, offering a clean, crisp sound that is not always found in commercial equivalents. Of greatest significance is that the receiver should be easily duplicated at a cost well under that of commercial units.

¹Circuit board templates are available from ARRL for \$1 and a large s.a.s.e.

²Circuit boards, negatives and many parts for this receiver are available from Circuit Board Specialists, P.O. Box 969, Pueblo, CO 81002.