A High-Performance Homebrew Transceiver: Part 4

Here is a complete description of the AF board.

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Designing and constructing the AF board of a radio is a relatively easy task. Op-amp circuits are perfectly predictable, special features can be added with little effort; signal levels are high and easily measured with simple equipment. The AF board in this radio contains the BFO amplifier, product detector, noise limiter, speech amplifier, balanced modulator and CW sidetone oscillator.

Part 1 gave a general description of the K5AM homebrew transceiver, built for serious DX work and contest operating.[1] Parts 2 and 3 described the IF and RF boards.[2, 3] This article gives circuit details for the AF board. A general description of this board was given in Part 1; the board is shown here in Fig 1. The block diagram in Fig 2 shows the arrangement of the various stages.

[1]Notes appear on page 56.

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Features

Some of the special features of the AF board are:

- High-pass transmit audio filter to eliminate hum.
- 60-Hz receive audio filter to eliminate hum.
- Electronic attenuators in all circuits with front-panel controls to avoid routing audio signals to the panel.
- Class-A audio output stage with only 0.3% total harmonic distortion.
- Noise limiter for reduction of atmospheric static.

Circuit Description: BFO and Carrier Amplifiers

Fig 3 gives the schematic for the stages used to provide LO injection power for the product detector and balanced modulator and that provide a carrier for CW operation. Special effort was made to prevent carrier leakage into the IF board during SSB operation. Both a switched MOSFET and a diode switch are used to gate the carrier. The total residual hum, noise and carrier on the transmitted SSB signal are more than 65 dB down.

Receiver Circuits

Fig 4 is the schematic of the stages used to process received audio signals. Signals arrive from the IF board at terminal σ9R1 and are fed directly to the product detector. Measuring LO injection at a DBM (doubly balanced mixer) is difficult with simple equipment. The diodes in the DBM cause distorted scope patterns at the LO port that are not easy to interpret as to power level. The 47-Ω resistor at the product detector's LO port helps isolate the port and allows meaningful readings at the test point indicated. The 2-V(P-P) level specified at the test point is estimated to correspond to a +4 dBm LO injection level. This is appropriate, although the device is rated at +7 dBm (see the discussion in Part 3).

A special low-noise op amp was selected for the first AF amplifier. Care was taken to install this low-noise amplifier immediately adjacent to the product detector to avoid hum pick-up on a connecting cable. The gain of the low-noise op amp is adjusted for 300 mV (P-P) at terminal σPD. The AM and FM detector circuits are adjusted similarly and the three JFET gates are used to select the appropriate detector.

Noise Limiter

As hams painfully know, noise blankers do not blank static caused by atmospheric thunderstorms or corona noise produced by high-tension power lines. In the eternal struggle to copy DX signals (no matter how weak) under noisy conditions (no matter how severe) hams have always been eager to try any conceivable noise-reduction method.

In times past, when AM was the primary mode for voice work on the ham bands, receivers had noise limiters. One common type was the shunt limiter, a diode clipper applied to the detected AF signal. In some radios, the clipping level was adjustable. Other radios had an automatic noise limiter that used the detected carrier—a dc signal sometimes also used to drive the S-meter—to establish an appropriate bias level for the clipping diodes.

Modern commercial receivers have no noise limiters. Many hams, especially 160-meter DX hounds, have used diodes on the headphone line to clip the noise. This can be very effective. A disadvantage is that the degree of clipping depends on the AF voltage level at the headphone jack, the headphone impedance and the AF gain (AFG) setting selected by the operator. The main disadvantage is that to obtain a fair amount of clipping, the receiver AF output level must be much higher than normal; this is likely to cause distortion in the receiver AF circuits, degrading signal intelligibility.

These problems are avoided by putting the noise limiter inside the radio, ahead of the **AF GAIN** control. Clipping at low AF levels is a simple matter. With no AM carrier to set the bias level, we cannot expect an automatic noise limiter, but we do want an adjustable noise limiter. We need a panel control to set the clipping level according to conditions. In Part 1, Fig 3, the **NOISE LIMITER** control is just below the meters, third knob from the left. The limiter is quite effective, especially with atmospheric static for weak low-band DX signals.

"Limiter" is a good term. It reminds us that the circuit cannot eliminate the noise, as a good blanker can under certain conditions, but that it only limits the noise to a level set by the operator. This level is usually the peak level of the desired signal, so that the noise and the signal are evenly matched in a fair contest to register in the operator's brain.

Receiver sensitivity measurements are based on the minimum discernible signal (MDS) specification. This means that the (S + N)/N is approximately 3 dB. Experienced DX operators know, however, that this ratio is no "minimum signal"—it is "arm-chair copy," or in other words, "loud." DX operators can copy CW signals that are well below the MDS. Thus, the limiter can turn barely detectable signals into reasonably good copy.

Don't expect the noise limiter to eliminate thunderstorms! Its effectiveness is only apparent on a narro range of weak DX signals, those within a few decibels of the ambient noise level. When signals fade below that level, nothing will help; when signals build up a few decibels, a noise limiter won't be needed. Still, most new countries added to an oper-ator's 160-meter DXCC list involve signals within that narrow range.

The noise limiter is normally used with the AGC on. This is the safest operating method (see Part 1, pp 21-22). Receiver gain is enough that ambient antenna noise on any band activates the AGC system. This insures that the AF level into the noise limiter is essentially constant. The resulting headphone volume is thus also constant. Signals do not "jump out the noise," as is often said about receivers reported to be "quiet." Such receivers merely have inadequate

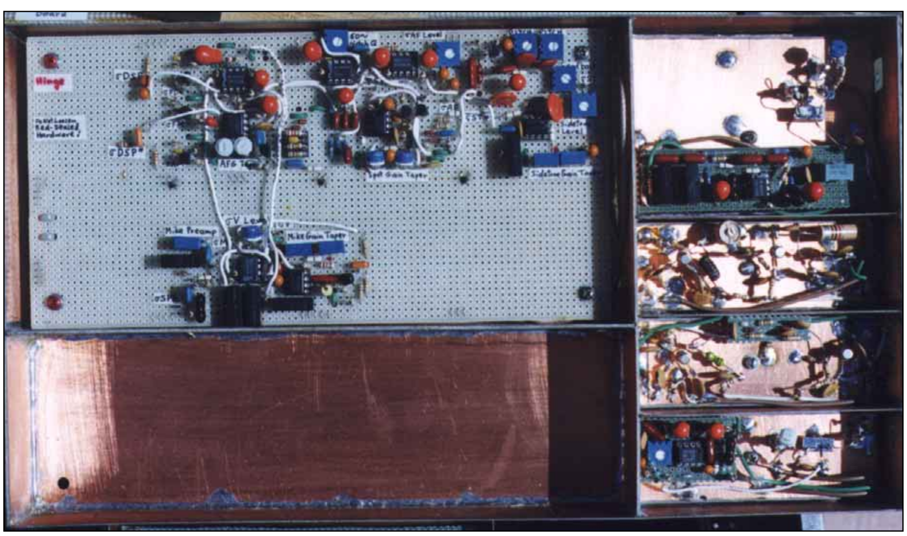
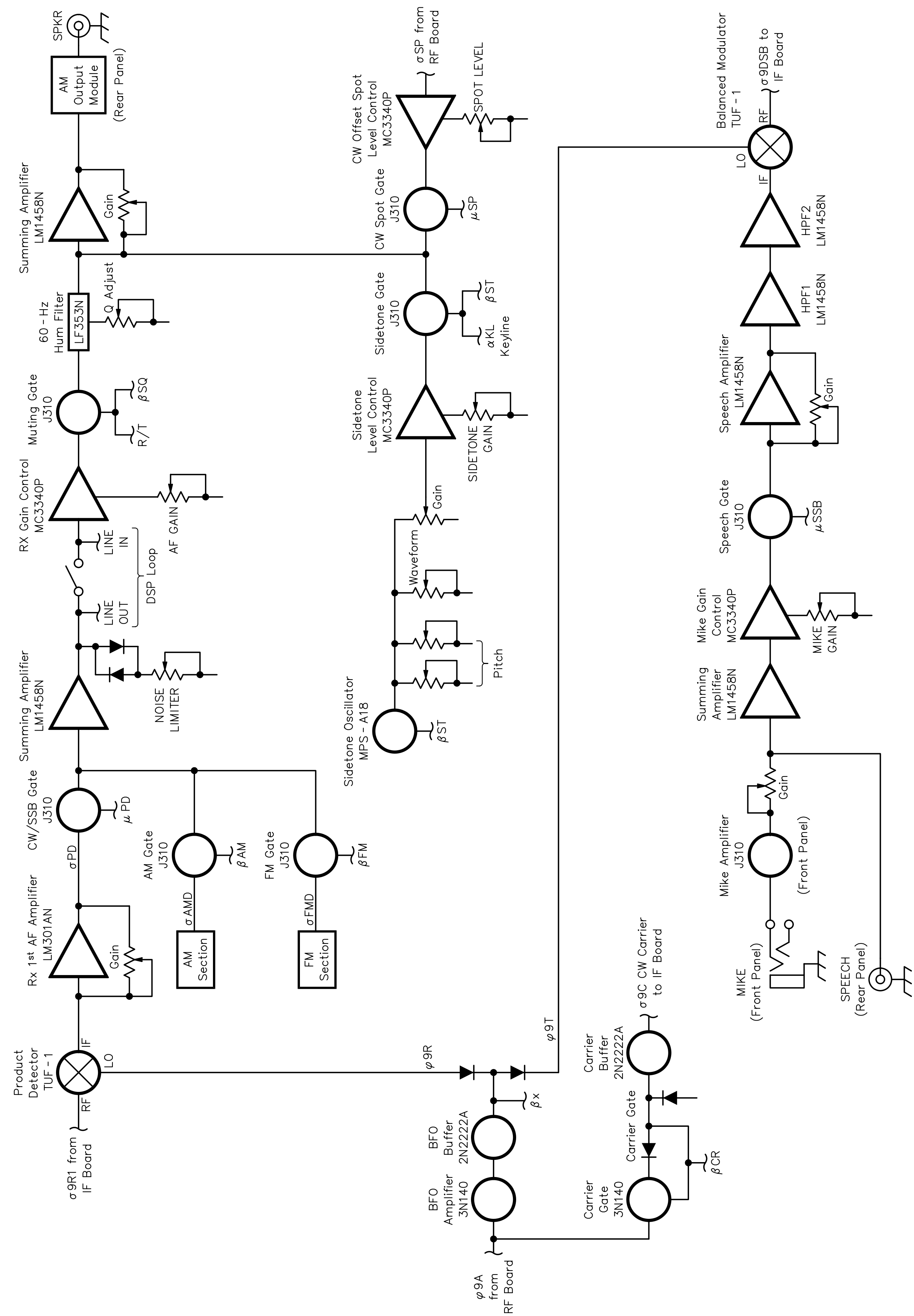


Fig 1—Top view of the AF board in the K5AM homebrew transceiver. At right, from the top, are the balanced modulator, the BFO amplifier, the carrier amplifier for CW and the product detector. The two-stage transmit high-pass AF filter is included in the balanced-modulator compartment, eliminating any possibility of hum pick-up on a connecting cable. Similarly, the first receiver AF amplifier, a special low-noise op amp, is included in the product-detector compartment. All other AF circuits are in the large compartment at the upper left; the lower left compartment is for the AM/FM circuits. (See Note 8.)

Fig 2 (see right)—AF board block diagram. Signals from the IF board arrive at terminal σ9R1. After detection, amplification and filtering, the audio signal travels from output terminal σAF to the audio-output module on the rear panel. For transmitting SSB, there are dual speech inputs: a MIKE jack on the front panel and a line-level jack on the rear panel. The DSB output is at terminal σ9DSB leading to the IF board, the SSB filters and RF speech clipper. Potentiometers labeled in all capital letters are front-panel controls; others are circuit-board trimpots for internal adjustment. An explanation of the terminal designators is given in Part 2, Table 1. The control lines are provided by the logic board.



SPKR
AM Output Module
(Rear Panel)
Summing Amplifier LM1458N
Gain
60 - Hz Hum Filter
LF353N
Q Adjust
Muting Gate J310
βSQ
R/T
RX Gain Control MC3340P
AF GAIN
LINE IN
DSP Loop
LINE OUT
Summing Amplifier LM1458N
NOISE LIMITER
CW/SSB Gate J310
μPD
σPD
AM Gate J310
βAM
FM Gate J310
βFM
Rx 1st AF Amplifier LM301AN
Gain
σAMD
AM Section
σFMD
FM Section
Product Detector TUF - 1
RF
IF
LO
σ9R1 from IF Board
φ9R
βx
BFO Buffer 2N2222A
BFO Amplifier 3N140
φ9A from RF Board
φ9T
CW Offset Spot Level Control MC3340P
σSP from RF Board
SPOT LEVEL
CW Spot Gate J310
μSP
Sidetone Gate J310
βST
αKL Keyline
Sidetone Level Control MC3340P
SIDETONE GAIN
Gain
Waveform
Pitch
Sidetone Oscillator MPS - A18
βST
Carrier Buffer 2N2222A
σ9C CW Carrier to IF Board
Carrier Gate
Carrier Gate 3N140
βCR
Balanced Modulator TUF - 1
σ9DSB to IF Board
HPF2 LM1458N
HPF1 LM1458N
Speech Amplifier LM1458N
Gain
Speech Gate J310
μSSB
Mike Gain Control MC3340P
MIKE GAIN
Summing Amplifier LM1458N
Gain
Mike Amplifier J310
(Front Panel)
MIKE (Front Panel)
SPEECH (Rear Panel)

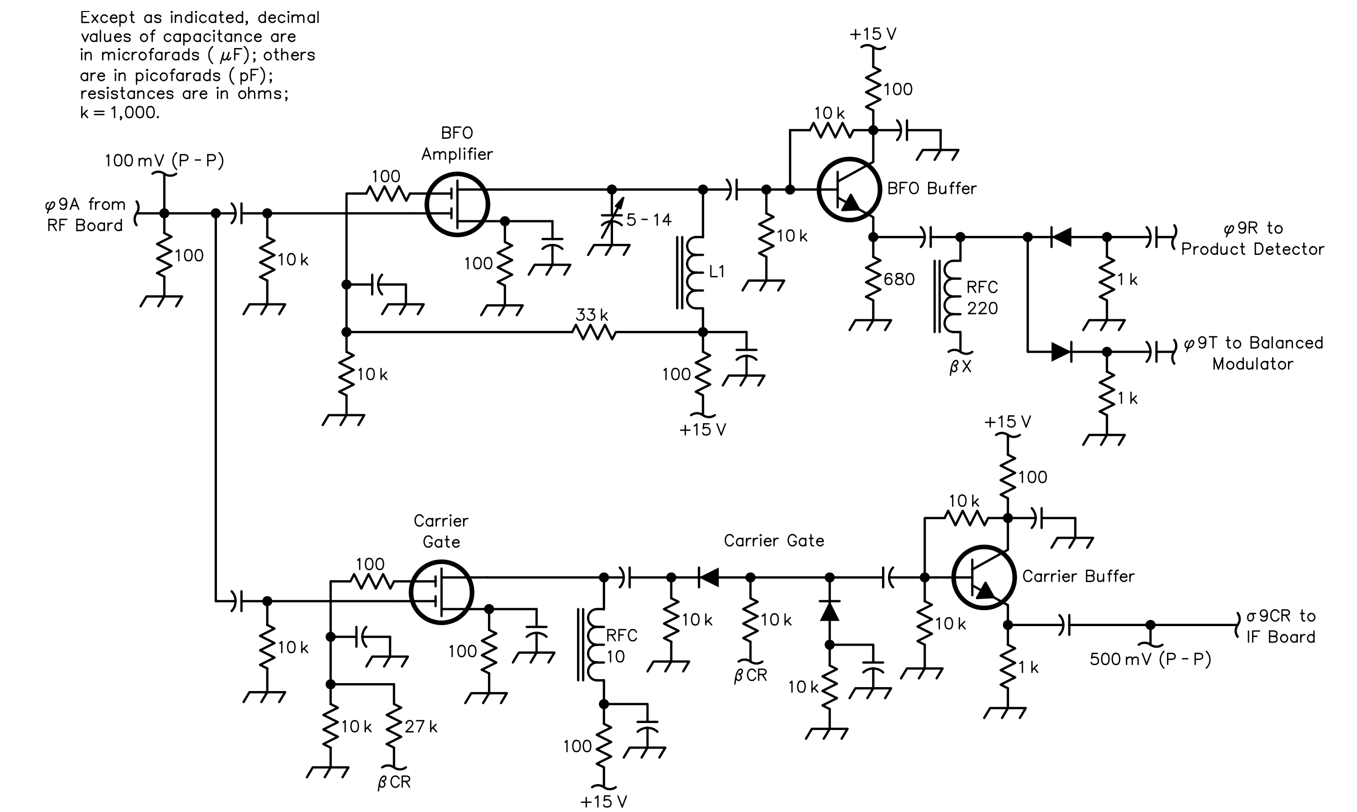


Fig 3—BFO and carrier-amplifier schematic diagram. Except as noted, each resistor is a 1/4-W, carbon-film type. All trimpots are one-turn miniature types, such as Bourns type 3386; Digi-Key #3386F-nnn. The unmarked coupling and bypass capacitors are all 10 nF disc ceramic types. Also, each control and power terminal has a bypass capacitor that is not shown. Electrolytic capacitors have 25-V ratings and values given in microfarads; those less than 100 µF are tantalum types. Capacitors labeled "s.m." are silver micas, with values given in picofarads. The values of RF chokes (RFC) are in microhenries. Part-supplier contact information appears in Notes 9, 10, 11 and 12.

The MOSFETs are all small-signal, VHF dual-gate types. Type 3N140 is used here, but any similar type may be substituted. Replacement-type NTE 221 is also available. The JFETs are J310s. Except where otherwise indicated, the diodes are small-signal silicon types, such as 1N4148; the bipolar transistors are type 2N2222A. Except as noted, the op amps are sections of LM1458Ns. Unless shown otherwise, each op amp is powered by the +15 V and –15 V rails. Not shown is the filtering at each op amp power terminal. This varies with the application. The minimum is a 100-nF, monolithic ceramic bypass. More sensitive and low-level circuits also use a 100-Ω isolation resistor and a 10-47 µF tantalum electrolytic at the terminal.

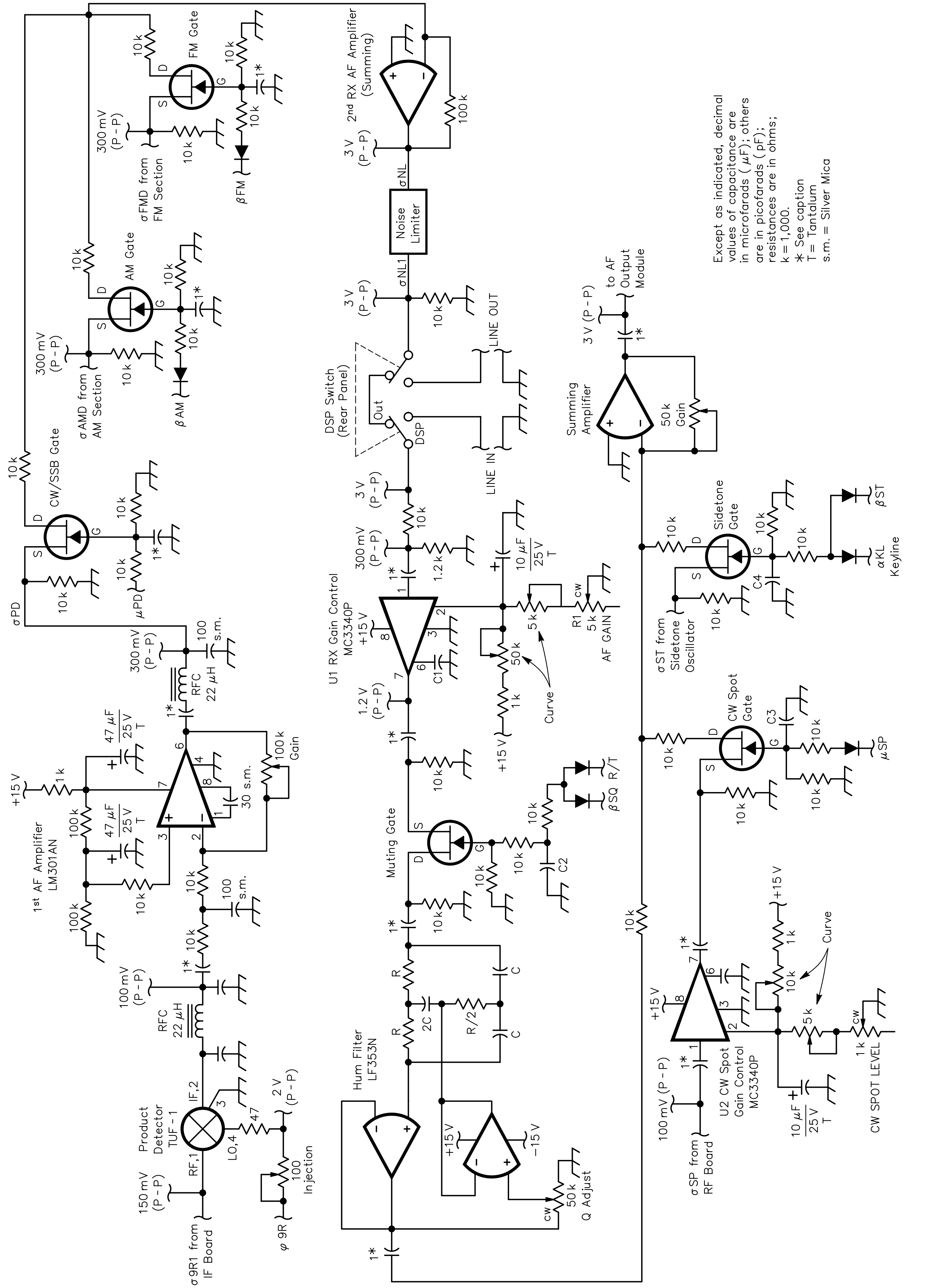
Potentiometers labeled in all-capital letters are front-panel controls; others are circuit-board trimpots for internal adjustment. The control lines are provided by the logic board. The signal levels indicated at various test points are scope readings.

L1—FT-37-61 ferrite toroidal core, 14 turns of #26 AWG enameled wire.

AGC systems; they are not necessarily "quiet" with regard to sensitivity or noise figure. Listening for weak signals in the noise on such receivers requires one to set the gain too high, creating an aural hazard when a strong signal suddenly appears. The flat AGC characteristic in this receiver allows the noise-limiter clipping level to be easily set. If "noise-jumping" signals are desired at other times, the IF GAIN control may be used to raise the AGC threshold (see Part 1, pp 21-22).

The noise-limiter circuit is shown in Fig 5. Op amp U1 raises the receiver AF level from 3 V to 14 V (P-P), while op amp U2 reduces it to the former level after the clipper. When clipping is used, however, the AFG control will need to be increased. With both controls on the

Fig 4—(see right) Receiver AF circuit schematic diagram. For general notes on the schematics, refer to the caption for Fig 3. Capacitors labeled simply "1" are 1-µF monolithic ceramics (see Note 10). The DBM used as a product detector may be obtained in small quantities directly from the manufacturer (see Note 12). Signal levels indicated on the diagram are given with the AF GAIN set for 2 W output with an 8-Ω resistive load at the speaker jack.
C—Polypropylene capacitor, 2.7 nF, 2% tolerance. Panasonic #ECQ-P1H272GZ, Digi-Key #P3272. Where 2C is indicated, use two of these in parallel; this ensures the closest match.
C1—Polypropylene capacitor, 1 nF. Panasonic #ECQ-P1H102GZ, Digi-Key #P3102.
C2—Polypropylene capacitor, 470 nF. Panasonic #ECQ-P1H474GZ, Digi-Key #P3474.
C3-C4—Polypropylene capacitor, 220 nF. Panasonic #ECQ-P1H224GZ, Digi-Key #P3224.
R—Metal-film resistor, 1 MΩ, 1% tolerance. Digi-Key #1.00MXBK. Where R/2 is indicated, use two of these in parallel; this ensures the closest match.
R1—AFG potentiometer, 5 kΩ. This has been replaced five times in the last eight years. The current resident, a 2-W wirewound type found at a hamfest, seems headed for a long life.
U1-U2—Electronic attenuator, Motorola MC3340P; discontinued. Available as replacement component NTE #829, Mouser #526-NTE829 (Mouser). A datasheet is available on the Web: http://www.mot-sps.com/books/dl128/pdf/mc3340rev6.pdf. Omitted from the schematic is the filtering at the +15-V supply terminal: a 100-Ω isolation resistor, a 100-nF monolithic ceramic capacitor and a 47-µF tantalum electrolytic capacitor at pin 8.



Product Detector
TUF-1
RF,1
LO,4
IF,2
σ 9R1 from IF Board
150 mV (P-P)
2 V (P-P)
φ 9R
100 Injection
RFC 22 μH
100 mV (P-P)
1st AF Amplifier
LM301AN
+15 V
47 μF 25 V T
100 k Gain
30 s.m.
100 s.m.
300 mV (P-P)
σ PD
μ PD
CW/SSB Gate
σ AMD from AM Section
β AM
AM Gate
σ FMD from FM Section
β FM
FM Gate
Hum Filter
LF353N
50 k Q Adjust
U1 RX Gain Control
MC3340P
Muting Gate
β SQ
R/T
Curve
R1 5 k AF GAIN
10 μF 25 V T
1.2 V (P-P)
3 V (P-P)
DSP Switch (Rear Panel)
Out
DSP
LINE IN
LINE OUT
σ NL1
Noise Limiter
σ NL
2nd RX AF Amplifier (Summing)
Summing Amplifier
50 k Gain
3 V (P-P)
to AF Output Module
σ ST from Sidetone Oscillator
Sidetone Gate
α KL Keyline
β ST
CW Spot Gate
μ SP
σ SP from RF Board
U2 CW Spot Gain Control
MC3340P
1 k CW SPOT LEVEL
Except as indicated, decimal values of capacitance are in microfarads (μF); others are in picofarads (pF); resistances are in ohms; k = 1,000.
∗ See caption
T = Tantalum
s.m. = Silver Mica

front panel, this is convenient; the clipping level is normally set according to conditions and not changed until the thunderstorm is over.

The clipping level is set by the **NOISE LIMITER** panel control. Voltage follower U3 is required to provide a low-impedance negative bias source for the negative-clipping diode. Inverter U4 tracks U3 and provides reverse bias to the positive-clipping diode of equal magnitude but opposite polarity. This insures that the positive and negative halves of the signal waveform are clipped equally. When the panel control is fully clockwise, the diodes have no reverse bias; each clips to 0.7 V. Thus the 14-V (P-P) level allows a maximum clipping depth of 20 dB. With the control fully counterclockwise, the diodes are completely reverse-biased, and the noise limiter is effectively off.

When noise limiting is needed for CW, the control is usually set near maximum; distortion on CW signals is of no consequence. For SSB, the full setting causes noticeable distortion, but signals are very intelligible. For less distortion, retard the control somewhat. With 6 dB of clipping, the distortion is barely noticeable. At those times when signals can be heard through the static without the limiter, use of the limiter makes listening far more pleasant and reduces fatigue. Also, the limiter can be left at 3-6 dB at all times; it won't noticeably effect the signals, but will reduce the noise from key clicks and splatter.

When a DX signal is too weak to hear during a static crash, the noise limiter still serves a valuable function and may enable an otherwise impossible contact. It saves the operator's ears! This is both a long-term safety feature and a short-term operating aid. An operator's hearing ability is depressed after some minutes of listening to loud noise. With the AFG high enough to hear a weak station between static crashes, one's hearing threshold may be degraded within ten minutes. On the other hand, if the gain is low enough so that static crashes don't cause desensitization, a weak station won't be heard. The solution to this dilemma is an adjustable noise limiter.

The noise-limiter schematic diagram is separated from the main diagram so that it might be built and installed in other receivers. Details and pin-outs are given. If the receiver AF level at the point of insertion is other than that specified the gain of the input and output amplifiers may be changed easily.

This noise limiter has been very helpful in DX work. One can only wonder: "Why don't all receivers have noise limiters?"

DSP Loop for External Filter

The DSP loop was added only a few years ago to accommodate a Timewave Model DSP-9+ filter. The loop is positioned before the **AF GAIN** control. This is done so that the AFG knob on the radio can be used independently of the filter. This avoids the usual cumbersome arrangement wherein the AFG on the radio must be continually readjusted for the proper input level and the AFG control on the external filter used to control headphone volume. This is the main reason for adding the DSP loop. There are also other problems:

- There is a 6-dB loss in the external filter between the line input and line output jacks.
- Signal levels are low and hum can be introduced.
- External devices installed on the speaker line can suffer from annoying RFI during transmissions.

The solution is to raise the AF level 20 dB for the loop and use an external amplifier to compensate for the loss in the filter. A simple 20-dB pad in the radio at the loop's return jack restores the AF signal to the original level.

The external amplifier is shown in Fig 6. It has controls to set the proper levels both to and from the filter. These need be set only once: The filter can be switched in or out at any time with no readjustment of receiver, amplifier or filter controls. This procedure eliminates the need for any modifications to the external DSP filter and allows adjustment for a variety of different external units. A switch on the rear panel of the radio cuts the loop out of the circuit. This avoids the need for a patch cable when the external filter is not connected. When connected, the filter is switched in and out by its own controls.

Electronic Attenuators

To avoid routing audio signals to front-panel controls and possible hum pickup, electronic attenuators are used for the **AFGAIN** function and all other front-panel audio level controls. The attenuators [MC3340Ps —*Ed.*] provide a 60-dB range, with a pin 2 control voltage range of 3-6 V. The maximum

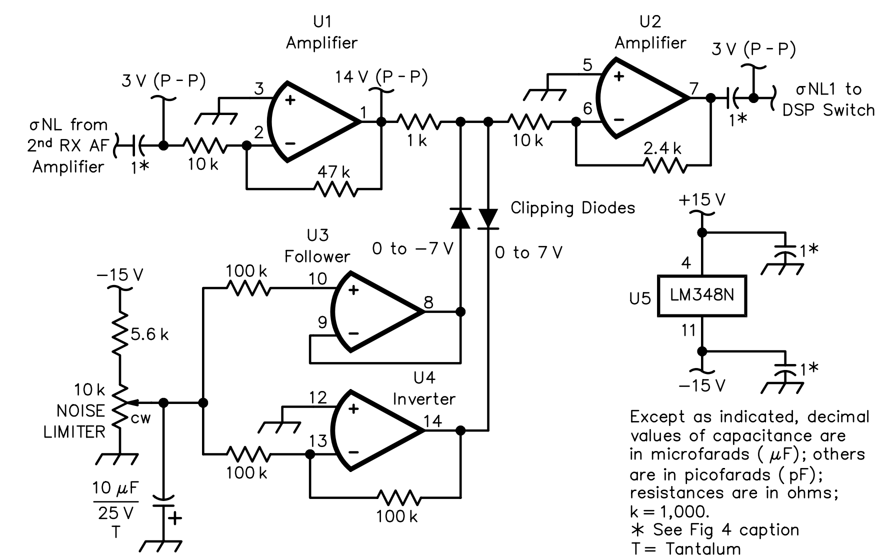


Fig 5—Noise-limiter schematic diagram. For general notes on the schematics, refer to the caption for Fig 3. The 1-kΩ resistor at the output of U1 is needed to prevent excessive current drain on U1 when the diodes conduct. The gain-setting resistors for U4, while they might be of any (equal) value to set the gain at –1, should be of no lower value than shown. The circuit of U4 establishes a virtual ground at the inverting input; a low-value input resistor would unduly load the potentiometer circuit, resulting in less available reverse bias. At the full counterclockwise position of the control, a reverse bias of 9 V is presented to the diodes. This is enough to cut off the diodes, since the peak AF voltage is 7 V in either direction. U—Quad op amp, LM348N. Each of the four op amps is shown separately. A fifth symbol shows the power connections, but all is contained in a single, 14-pin DIP package. Note that while type LM324N is used in other parts of the radio, it is a single-supply type vulnerable to crossover distortion. It is useful for dc-control circuits because it has a wider output voltage swing, but it should not be used for AF. The dual LM1458N and quad LM348N types used on the AF board are standard low-distortion 741 types.

voltage gain of the attenuators is four. The circuits are configured for 300-mV (P-P) input, with output varying from 1.2 to 1200 mV (P-P). This same setup is used for the **MIKE GAIN**, **SIDETONE LEVEL** and **CW OFFSET SPOT LEVEL** circuits. (One attenuator for each circuit.) Each of these circuits requires only a single, unshielded dc lead to the front panel. Simplicity of wiring and avoidance of hum was well worth the extra trouble of installing the ICs.

I like the normal operating positions of all controls to be between 10 and 11 o'clock, with 40-dB of gain reduction at the full counterclockwise position and 20-dB increase when fully clockwise. Satisfying this particular demand was more difficult than expected—the characteristics of the devices varied from sample to sample. Each circuit requires two trimpots to set the desired curve, and the adjustments interact greatly. Alignment was a bit tedious, but the attenuator circuits have functioned perfectly and have required no further attention.

Muting Gate

After the attenuator is the JFET muting gate, used for TR switching and squelching. The deceptively innocent-looking capacitor, C2, in the source circuit deserves attention. Since all other circuits in the radio are quite fast, this capacitor determines receiver recovery time. Some delay is needed, or the radio will squeal in protest for a few milliseconds at the end of each transmission, or after each dit or dah when operating CW QSK. Too much capacity here will cause excessive delay and destroy the radio's break-in ability. On the other hand, too little capacity will allow clicks to be heard in the headphones. The divider for the blocking voltage also affects the timing. The circuit shown here mutes the receiver smoothly and quietly. Stations can be heard breaking in while the radio is transmitting CW at 50 wpm.

60-Hz Notch Filter

The next stage is an adjustable-Q 60-Hz notch filter.[4] It eliminates any hum, whether from internal circuits or included on received signals. The component values specified result in a calculated notch frequency of 58.9 Hz. The component manufacturers' tolerances result in a worst-case error of 1.7 Hz. This possible error is one reason for using an adjustable-Q filter: to ensure that the notch includes 60 Hz. The trimpot is adjusted to obtain a 3-dB band-reject range of about 55-65 Hz. Measured

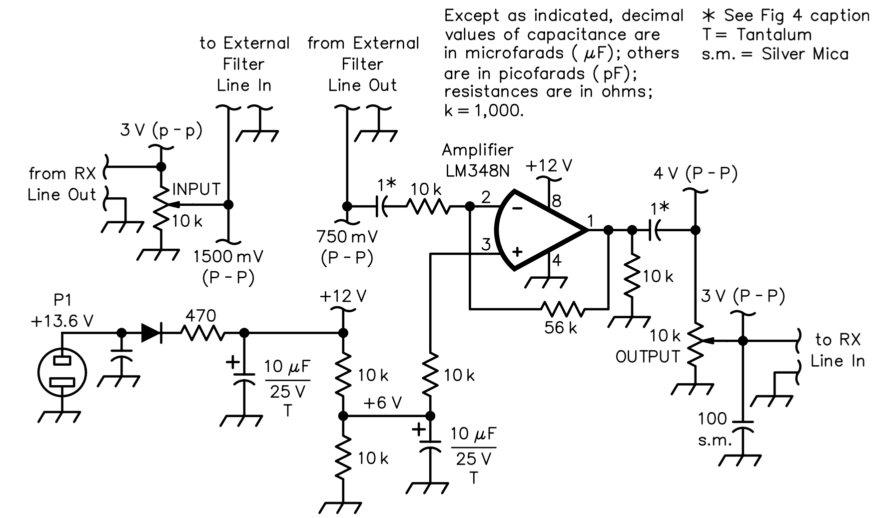


Fig 6—External-DSP-loop-amplifier schematic diagram. For general notes on the schematics, refer to the caption for Fig 3. The amplifier may be housed in a small aluminum box. Defense against RFI from the transmitting antenna is not critical, since the amplifier and filter are positioned before the receiver muting gate.
The amplifier is powered by the same 13.6-V dc power supply used for the numerous operating-bench auxiliary gadgets. The amplifier is fitted with a 6-foot shielded power cable terminated in a two-pin Jones plug. The 13.6-V dc fused distribution boxes on the operating bench contain two-pin Jones sockets. These connectors are solid, reliable and easy to use. Since the shack has them only for this purpose, this system is safer than one that uses other common connectors, such as phono plugs.
P1—Jones plug, two-pin, Cinch #P-302-CCT, Digi-Key #CJ102P. Mating socket, Cinch #S-302-AB, Digi-Key #CJ302S.

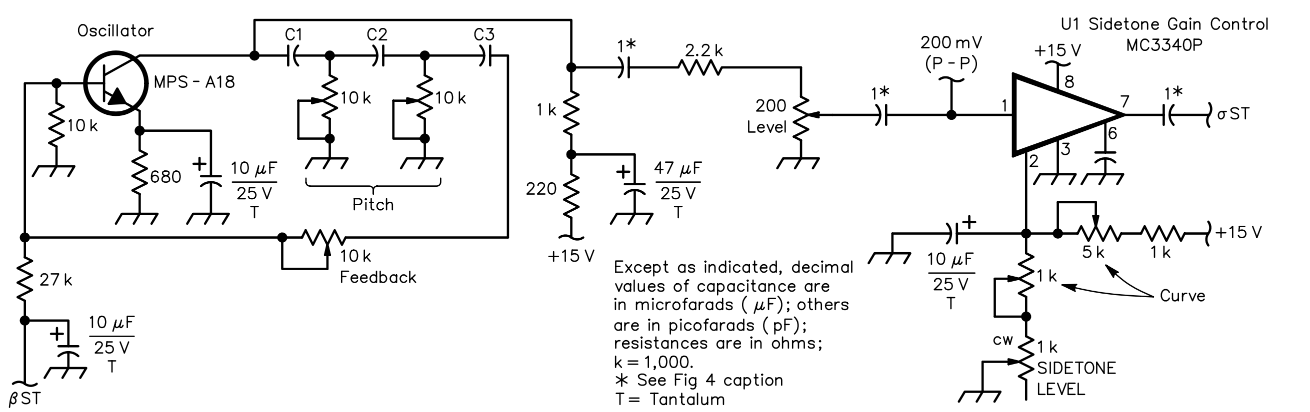


Fig 7—Sidetone-oscillator schematic diagram. For general notes on the schematics, refer to the caption for Fig 3.

C1-C3—Polypropylene capacitor, 47 nF. Panasonic #ECQ-P1H473GZ, Digi-Key #P3473.

U1—MC3340P. See caption for Fig 4.

notch depth is 50 dB.

The notch filter circuit is a modern version of the traditional "twin-T" network. The network alone has a Q of only 0.3, but with feedback derived from the upper voltage-follower op amp, the Q can be adjusted from 0.3 to more than 50. The trimpot determines the amount of feedback. The lower voltage follower is needed to drive the network from a low-impedance source so the circuit is unaffected by the resistance of the trimpot. Notch depth depends on component match (see Note 4).

The last stage is a summing op amp that combines the signals from the detectors, sidetone oscillator and CW-offset spot mixer on the RF board. The gain of the summing-amplifier stage is adjusted to provide the correct audio signal level at terminal σAF, which leads to the AF output module on the rear panel.

Sidetone Oscillator

The sidetone oscillator is shown in Fig 7. Adjustments are provided for pitch, feedback and output level. The feedback control was originally intended to allow adjustment for the minimum amount needed to sustain oscillation, thus to obtain the purest-possible sine wave. However, a pure sine wave may produce fatigue over long operating periods. The feedback control may be used to introduce some harmonic distortion, which may result in a more pleasant sound. Recall that a good violin produces many nice-sounding harmonics. When in either **TUNE** or **PULSE TUNE** mode, the sidetone oscillator is disabled.

AF Output Module

The AF-output module is mounted on the transceiver rear panel, with the output transistors using the panel as a heat sink. The circuit is shown in Fig 8. Two stages of low-pass filtering are used, each with a 3-dB cut-off frequency of 3000 Hz. The measured composite response is –3 dB at 2500 Hz and –6 dB at 3000 Hz.

Each filter stage is a unity-gain, maximally-flat Butterworth filter with:

$$Q = \frac{\sqrt{2}}{2} \qquad \text{(Eq 1)}$$

in a voltage-follower configuration.[5] This configuration is the simplest to apply with respect to component selection. It also involves the simplest formulas. One first chooses the cut-off frequency, f (in Hz), and the capacity, C (in farads). Then the resistance R (in ohms) is simply:

$$R = \frac{1}{2\sqrt{2}\,\pi f C} \qquad \text{(Eq 2)}$$

The 10-kΩ resistor at the non-inverting input does not affect the response; it serves merely to protect the op amp (see Note 5, p 126).

The output stage operates class A. The biasing is chosen for 50 mA idling current. Total harmonic distortion (including hum and noise) of the AF-output module measures 0.3% at normal levels and 1.5% at the full 2-W output. In a test involving the entire receiver, an RF signal on the 20-meter band produced total harmonic distortion (including hum and noise) of 0.6% at normal levels.

Transmit Circuits

Fig 9 is the schematic of the stages used for transmitting. The speech amplifier has two alternative inputs. The front-panel **MIKE** jack is rarely used. I don't like a clutter of cables on the operating bench or protruding plugs that impede control-knob access. I always use the rear panel **SPEECH** jack.[6] This jack provides a high-level, 600-Ω line input and accepts speech signals from the station's speech-distribution system and the digital voice keyer.[7] Running this input at a high-level minimizes hum pick-up—often a problem when digital voice recorders are used. The nominal input levels are 30 mV (P-P) at the front-panel **MIKE** jack and 300 mV (P-P) at the rear-panel **SPEECH** jack. The inverting op-amp summing stage combines the two inputs with no interaction.

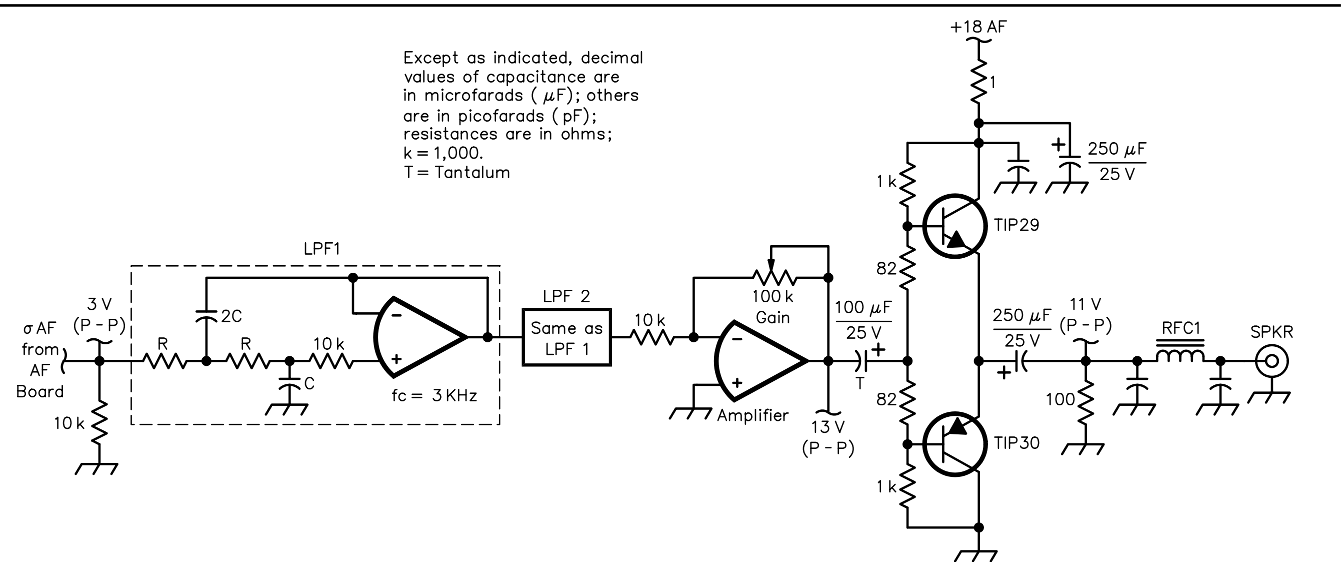


Fig 8—AF-output-module schematic diagram. For general notes on the schematics, refer to the caption for Fig 3. The 1-Ω resistor in the +18-V supply line to the output stage is a shunt for current metering during tests. A DMM set to the millivolt range will read out in milliamps directly. These 1-Ω shunts are also included at many other points in the radio where a current measurement is required. The complementary-output transistors are available at Hosfelt.

C—Polypropylene capacitor, 1 nF, 2% tolerance. Panasonic #ECQ-P1H102GZ, Digi-Key #P3102. For 2C use two of these in parallel; this insures the closest match.

R—Metal-film resistor, 37.5 kΩ, 1% tolerance. Digi-Key #37.5KXBK.

RFC1—RF choke, 10 μH. The choke must have a dc resistance of 1 Ω or less.

The JFET microphone amplifier is located directly at the front panel on a very small circuit board attached to the jack. This minimizes hum pick-up. A single shielded lead runs from this board to the AF board. The microphone amplifier will accept high-impedance mikes; for low-impedance mikes, an appropriate load resistor must be provided externally. For my Heil HC-5 mikes, I install a 2.2-kΩ resistor in the mike plug. This arrangement provides the greatest flexibility (see Note 7). The RC network at the mike jack filters RF. Silver-mica and polypropylene capacitors are used for their low-noise characteristics.

After the summing amplifier, there is an electronic attenuator for **MIKE GAIN** control. It is adjusted as described above in the "Receiver Circuits" section. The electronic attenuator avoids the need to route speech signals to the front panel, again minimizing hum pick-up. Capacitor C2 at pin 6 of the attenuator is for high-frequency roll-off; it may be altered as desired. The value given for C2 results in a 3-dB roll-off at 5 kHz. After the attenuator is a JFET gate. This, along with switched stages on the IF board, eliminates any possibility of modulation during **CW** or **TUNE** operation. The next op amp drives the high-pass filter.

High-Pass Filter

Two stages of high-pass filtering are used, each have a 3-dB cut-off frequency of 300 Hz. The measured composite response is –3 dB at 380 Hz and –50 dB at 60 Hz. Care was taken to install the high-pass filter immediately adjacent to the balanced modulator, thus eliminating any possibility of hum pick-up on a connecting cable.

Each stage is a unity-gain, maximally-flat Butterworth filter with

$$Q = \frac{\sqrt{2}}{2} \qquad \text{(Eq 3)}$$

in a voltage-follower configuration (see Note 5). This configuration is the simplest to apply in regard to component selection. It also involves the simplest formulas. One first chooses the cut-off frequency *f* (in Hz) and the capacity *C* (in farads). Then the

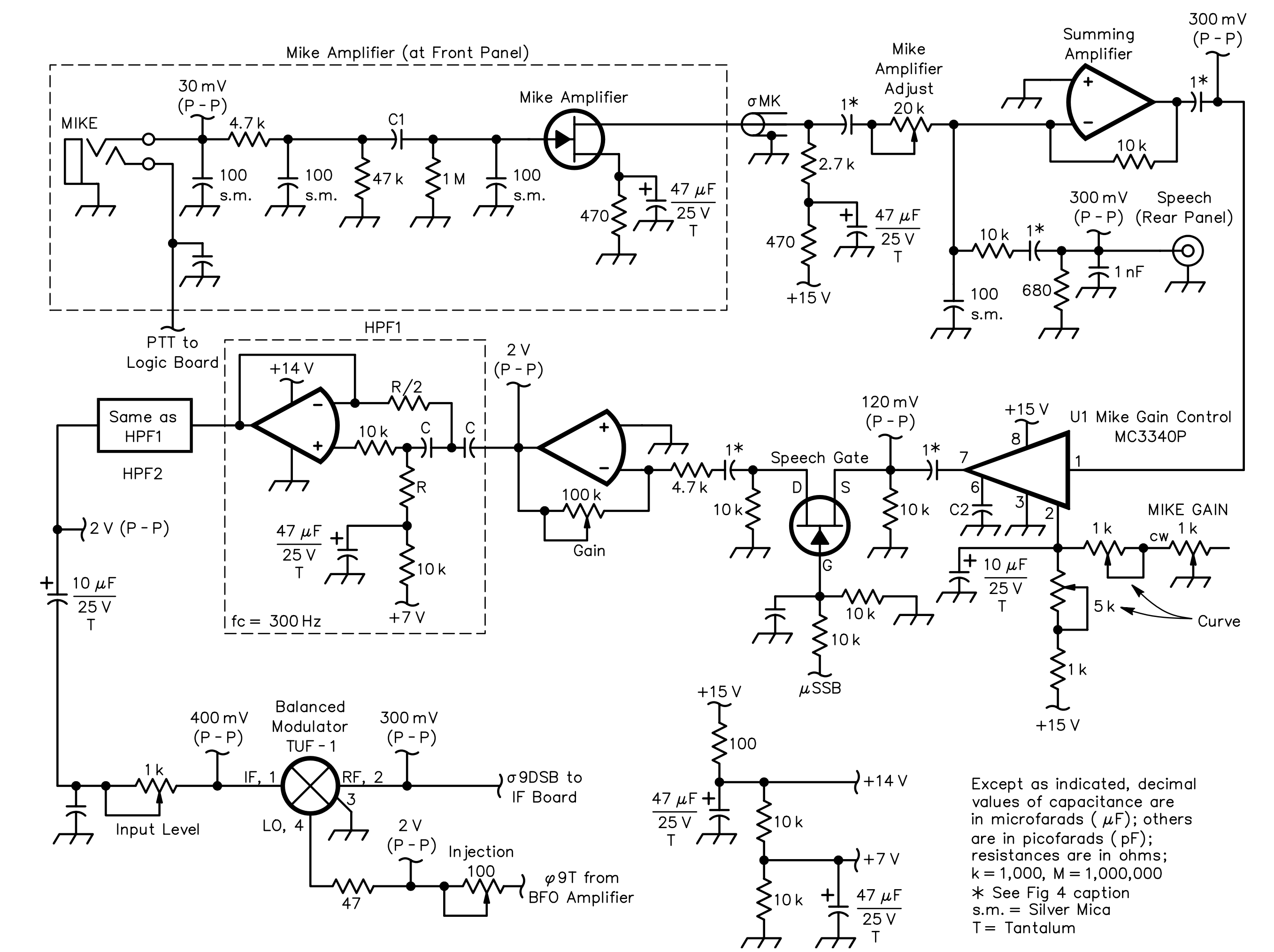


Fig 9—Transmitter AF-circuit schematic diagram. For general notes on the schematics, refer to the caption for Fig 3. The signal levels after the mike-gain attenuator are given for the normal control-knob position of 11 o'clock (see Part 1, p 21 for information about microphone calibration). The DBM used as a balanced modulator may be obtained in small quantities directly from Mini Circuits.

C, C1—Polypropylene capacitor, 10 nF, 2% tolerance. Panasonic #ECQ-P1H103GZ, Digi-Key #P3103.

C2—Polypropylene capacitor, 5.6 nF. Panasonic #ECQ-P1H562GZ, Digi-Key #P3562.

R—Metal-film resistor, 75 kΩ, 1% tolerance. Digi-Key #75.0KXBK. For R/2 use two of these in parallel; this insures the closest match.
U1—MC3340P. See caption for Fig 4.

resistance R (in ohms) is simply:

$$R = \frac{1}{\sqrt{2}\pi\, f\, C} \qquad \text{(Eq 4)}$$

With a fixed value of C, the cut-off frequency may be changed (within limits) by simply using the inverse relation between f and R. For example, with the value shown for C, a cut-off frequency of f = 200 Hz can be obtained with R = 112.5 kΩ. The 10-kΩ resistor at the non-inverting input does not affect the response; it simply protects the op amp as previously described. The 10-kΩ filtering resistor at the +7-V bias supply point also does not affect the response; the 47-µF capacitor provides a virtual AF ground for the network.

Construction

The AF board is built as shown in Fig 1. The general method of construction was described in Part 1, where the need for careful shielding and lead filtering was discussed. The power and control leads are filtered as described in Part 2. Most of the purely-AF circuits are hand-wired on perf boards. Plain copper board and truly "ugly" construction is used for all circuits containing 9-MHz signals. The board's underside is shown in Fig 10.

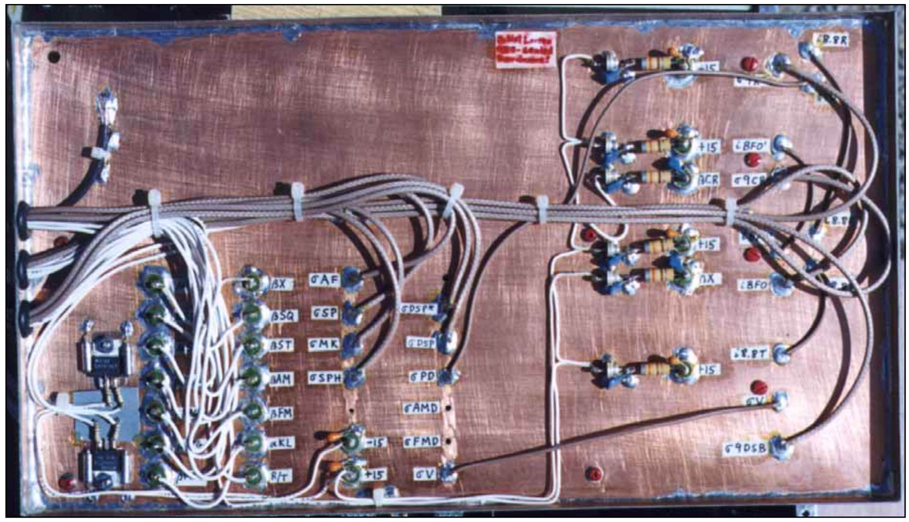


Fig 10—Bottom view of the AF board. Effective filters are installed at each terminal and coax cables are soldered directly to the double-sided circuit board (see the discussion in Part 2). To minimize connector troubles, the board is hard-wired to the radio; a 12-inch-long bundle of wires and cables allows the board to be easily lifted and serviced.

Test and Alignment

Normal operating levels at various points of the circuit are indicated on the schematic diagrams. The associated trimpots are adjusted to obtain the specified oscilloscope readings. There are quite a few trimpots in the radio. When building a single unit, it is often easier to install a trimpot than to individually select a component. This minor expense is justified by saving of hours of work in selecting and changing components. This is especially true when a radio is designed and built stage-by-stage. Often, a section is built without full knowledge of what lies ahead. Desired levels are apt to change in the light of final testing. None of the trimpots has required readjustment since the radio was built. Exceptions occur when modifications are introduced; then the trimpots become especially useful.

Summary

This article gives a complete description of the AF board in a high-performance homebrew transceiver. Double-balanced mixers are used for both the product detector and the balanced modulator. Special filters are included to avoid hum both in reception and in the transmitted signal. As in the remainder of the radio, flexibility and operating convenience are prime design factors.

Notes

[1]M. Mandelkern, K5AM, "A High-Performance Homebrew Transceiver: Part 1," *QEX*, Mar/Apr 1999, pp 16-24.

[2]M. Mandelkern, K5AM, "A High-Performance Homebrew Transceiver: Part 2," *QEX*, Sep/Oct 1999, pp 3-8.

[3]M. Mandelkern, K5AM, "A High-Performance Homebrew Transceiver: Part 3," *QEX*, Nov/Dec 1999, pp 41-51.

[4]R. C. Dobkin, "High Q Notch Filter," Linear Brief #LB-5, in *Linear Applications Handbook*, National Semiconductor Corp, Santa Clara, California, 1980.

[5]W. Jung, *IC Op-Amp Cookbook* (Indianapolis: Howard W. Sams and Co, 1974), pp 331-333.

[6]Similarly, I don't use the front-panel **HEADPHONE** jack, but only the rear-panel **SPEAKER** jack. On the operating bench is a 40-year-old speaker/headphone switch box with a headphone-level control for equalization. This provides instant switching without fussing with the headphone plug or readjusting the AFG.

[7]M. Mandelkern, K5AM, "The AMSAFID: An Automatic Microphone Switcher Amplifier Filter Integrator Distributor," *QST*, Nov 1995, pp 47-49.

[8]Sharp-eyed readers may notice that the AM/FM compartment is empty. This only proves that this shack follows true ham-radio tradition: Nothing is ever really finished.

[9]Digi-Key Corporation, 701 Brooks Ave S, PO Box 677, Thief River Falls, MN 56701-0677; tel 800-344-4539 (800-DIGI-KEY), fax 218-681-3380; **http://www.digikey.com/**.

[10]Hosfelt Electronics, 2700 Sunset Blvd, Steubenville, OH 43952; tel 800-524-6464, fax 800-524-5414; E-mail **hosfelt@clover.net**; **http://www.hosfelt.com/**.

[11]Mouser Electronics, 2401 Hwy 287 N, Mansfield, TX 76063, tel 800-346-6873, fax 817-483-0931; E-mail **sales@mouser.com**; **http://www.mouser.com/**.

[12]Mini Circuits Labs, PO Box 350166, Brooklyn, NY 11235-0003; tel 800-654-7949, 718-934-4500, fax 718-332-4661; **http://www.minicircuits.com/**.

See Part 5 in March/April 2000 *QEX*