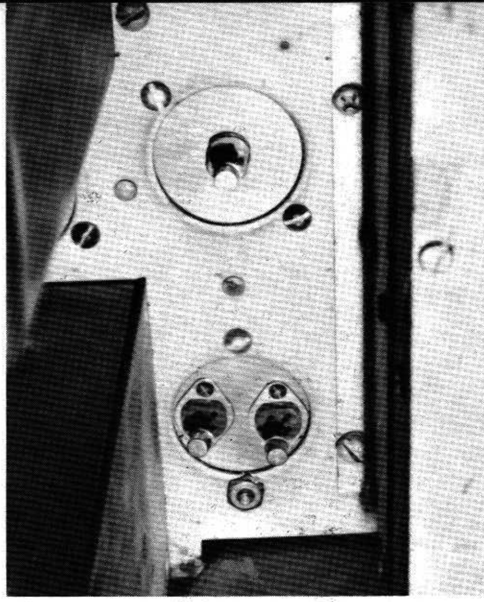
MOSFETs for Tubes

Substitutions in the Old Receiver


Mounting the transistors is easy if metal plates are substituted for the original tube sockets. The tube socket area readily will accommodate all the transistor sockets necessary for replacing the tube in question.

BY ALBERT D. HELFRICK,* K2BLA

Any enterprising amateur can create his own hybrid or complete solid-state receiver for a bargain price with metal-oxide field effect-transistors (MOSFETs). The feature of MOSFETs that sets them aside from regular bipolar transistors is the similarity of their characteristics to vacuum tubes. It is this similarity that allows one to make almost direct substitution of MOSFETs for vacuum tubes.

Unlike bipolar transistors, MOSFETs are voltage-controlled devices, hence they have a high-impedance input. For example, the dc input resistance of a MOSFET can be greater than 10^{15} ohms. Although the input resistance at high frequencies is quite a bit less, it is considerably higher than that of bipolar devices. Very good power gains can be obtained for excellent sensitivity.

Most important, field-effect transistors have low noise figures because they are majority-carrier devices. The noise in bipolar devices is mainly due to recombination of minority carriers in the base. Also because operation does not depend on minority carriers, MOSFETs are less sensitive to temperature than bipolars.

The following are a few pointers for converting one or all the stages of a vacuum tube receiver to MOSFETs:

Start with a working receiver. (It is not necessary that the receiver be up to factory specs, but it is most helpful to make sure the receiver works properly in its original form before beginning the conversion.)

The first step is to obtain a low-voltage supply for the MOSFET circuits, since few receivers have a suitable supply. The best method is simply to construct a half-wave rectifier with one good-sized filter capacitor, using the existing heater winding on the power transformer. Be sure that one side of the heater supply is connected to ground — if it is not, it would be best to build a separate supply. Heater supplies at 6.3 volts rms will supply about 9 volts with a half-wave rectifier and a large filter. Twelve-volt heater lines will supply twice that value. The supply should be capable of providing about 3 mA for each MOSFET circuit installed. There is no danger of overloading the heater windings because, as each tube is removed to make way for a MOSFET, the reduction in filament current is at least 150 mA, which is more than a whole MOSFET receiver!

In order to gain the most from each stage, the rf, mixer, local-oscillator, and i-f stages should be modified in that order, thus allowing one to stop the conversion when one desires.

RF Amplifiers

Fig. 1 shows a typical rf or i-f amplifier, simplified by eliminating band-switching or band-spread circuits. Locate the B+ feeder (point X) and disconnect B+ from the rf stage. It may be advantageous to disconnect the screen supply for safety's sake.

Usually, the values of the source bypass capacitor and source bias resistor are far from critical except perhaps in the mixer where correct

* 70-A Linn Drive, Verona, N. J. 07044

Once it was the fashion to pep up an old receiver with newer and better tube types. Now it's FETs, with promise of even better performance. Here are some suggestions from K2BLA, who has done just exactly this to modernize an old Super-Pro.

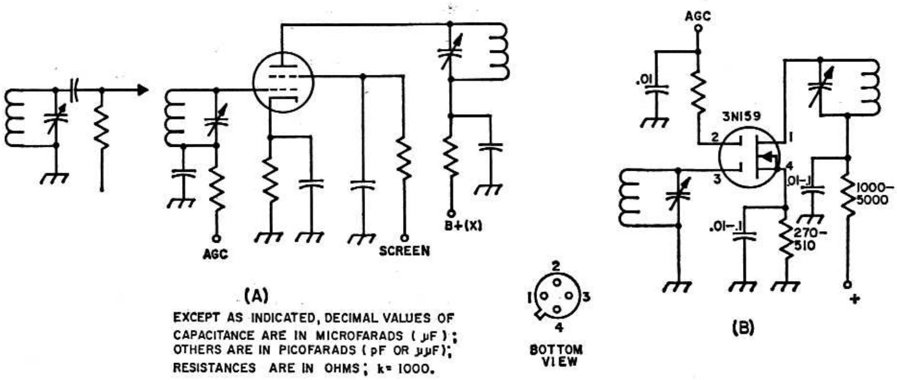


Fig. 1—A—Typical rf or i-f basic amplifier circuit used in many communications receivers. Switching details etc., have been omitted as they are not affected by MOSFET substitution.

B—Substituting a MOSFET is relatively simple: the drain corresponds to the tube plate, gate to grid and source to cathode. A modification of the overall agc circuit may be needed since the agc voltage should go from +1 or +1.5 volts with no signal to about zero volts at maximum signal. One way to get the positive voltage is to insert a 1.5-volt dry cell in series with the main agc bus.

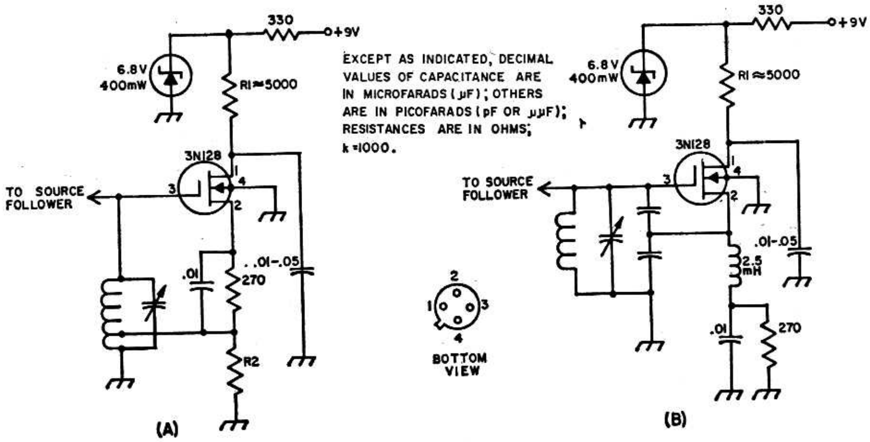
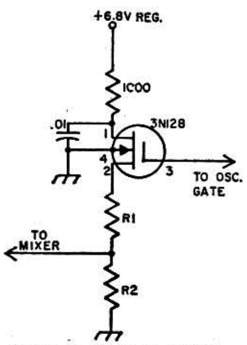


Fig. 2—Hartley and Colpitts MOSFET oscillators. The values of R_1 and R_2 are chosen to adjust the rf voltage to safe limits, as explained in the text.



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (µF); OTHERS ARE IN PICOFARADS (pF OR µµF); RESISTANCES ARE IN OHMS; k =1000.

Fig. 3—Source follower for coupling oscillator to mixer. The sum of R_1 and R_2 should be of the order of 1000 ohms; adjust the ratio of R_2 to the total resistance so that the rf voltage fed to the mixer is about 2 volts peak to peak.

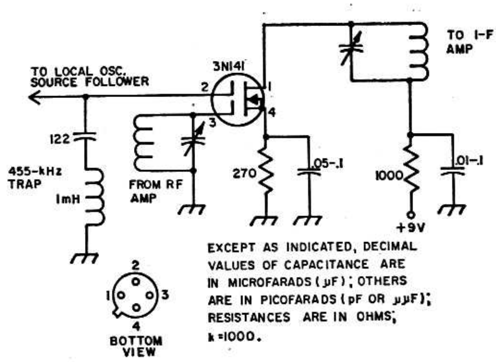
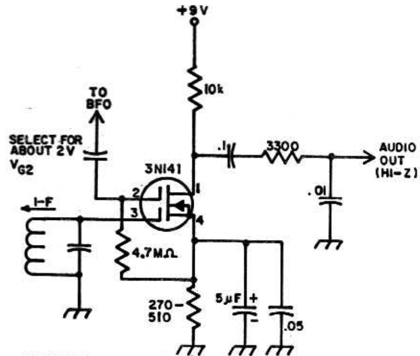


Fig. 4—Dual-gate MOSFET mixer circuit, with signal and oscillator voltages fed to separate gates.



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (µF); OTHERS ARE IN PICOFARADS (pF OR µµF); RESISTANCES ARE IN OHMS; k = 1000.

Fig. 5—The product detector closely resembles the mixer circuit, except that the beat-frequency output is in the audio instead of the i-f range.

bias is necessary for reduced spurious responses. The original cathode bias resistor may be a close value, and if so it's a safe bet that the bypass capacitor is large enough. The plate decoupling resistor will most likely be too large, but it is a simple matter to shunt another resistor across it. For dual-gate devices, a dry cell can be used to supply 1.5 volts for gate No. 2. This will allow simple transistor-for-tube substitution with only B+ change to evaluate the performance.

Single-gate devices have considerable drain-to-gate capacitance and they must be neutralized; however, the dual gate devices have much less drain-to-gate capacitance and may be operated unneutralized. Remember, MOSFETs are extremely high-impedance devices, so if self-oscillations occur check lead placement, then neutralize.

It is necessary to have some reliable signal source at a constant amplitude to check for improvement in sensitivity and as a signal for experimenting with parts values. Be sure not to exceed current and voltage ratings of the devices while experimenting with parts values.

This simple tube-to-MOSFET change should provide a working circuit the first time, and with little circuit change, it should bring an improvement in sensitivity, image rejection and improved overload characteristics.

Local Oscillator and Mixer

Receiver improvement from a MOSFET mixer is marked. If the receiver has a pentagrid converter it is necessary to replace it with an oscillator-mixer type converter (there is no FET equivalent of a pentagrid mixer tube).

Most receivers use either Hartley or Colpitts oscillators. Fig. 2 shows two MOSFET oscillator circuits. Determine what kind of tuned circuit the receiver has, and then which oscillator circuit is best suited.

One word of caution here: The MOSFET transistors used by the author were rated at 30 volts maximum peak-to-peak gate voltage, and the peak-to-peak gate voltage using the original tapped coil was greater than 40 volts. When constructing the oscillator circuit, set the receiver oscillator to its lowest frequency and use an oscilloscope to determine the peak-to-peak voltage at the gate terminal. Be sure to use a high-impedance probe and an oscilloscope with sufficient band-width. A good quality VTVM could measure the rms value of the gate voltage. Assuming the waveform to be sinusoidal, multiply by 2.8 to determine the peak-to-peak voltage. If the gate voltage is excessive, increase the source resistance and, if necessary, add R^2.

To minimize oscillator pulling and to attenuate the large voltage from the oscillator, a source follower is recommended (Fig. 3). Try to limit the peak-to-peak voltage to the mixer to 0.75 to 1 volt. Larger injection voltages will cause spurious responses. Also, the dc voltage across the source resistor should be about 0.1 to 0.4 volt.

The dual-gate MOSFET mixer is one of the best mixers available. With proper operating conditions, it offers good cross modulation attenuation, dynamic range, and practical immunity from spurious responses. Fig. 4 shows a typical mixer circuit. Notice that the divider of the source follower (Fig. 3) is connected directly to the second gate of the mixer. This supplies the necessary positive bias to the second gate of the mixer. Remember, high-impedance, high-frequency circuits require short, rigid leads for stability.

Other Circuits

Intermediate-frequency amplifiers may be converted in the same manner. It is advisable to use dual-gate devices wherever possible. The second gate is used for agc control, and the more stages under agc the more effective the action. The low feedback capacitance usually allows unneutralized operation.

The MOSFET product detector, being a mixer, like the mixer offers excellent results.

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Table I

Stage	*Type*
*Rf amp. I and II	3N159
Mixer	3N141
Hf osc. and source foll.	3N128
*I-f I and II	3N159
I-f III	3N128
Product Det.	3N141
BFO	3N128
Agc amp.	3N128
Calibrator	3N128
Audio amp.	Integrated circuit
Power output	2N301 (bipolar)
S-meter differential amp.	Junction FETs

3N128 — Single gate type
3N141, 3N159 — Dual gate types

* Agc controlled stage.

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Most old receivers have no product detector other than the usual diode-BFO combination. Although it may be desirable to include a more elaborate one, the necessity for a switch to change from the product detector to a diode may discourage this. However, if a diode detector is not desired — i.e. only ssb or cw reception is wanted — the product detector circuit in Fig. 5 gives excellent results.

Conclusion

MOSFETs can be used to replace any vacuum tube in a typical receiver except in the audio output and power supply. In addition to the circuits already discussed, recent editions of *The Radio Amateur's Handbook* contain other MOSFET circuits which may be used in a conversion.

The use of transistor sockets allows experimenting with different devices and makes for easy construction. Drill out the rivets on the tube sockets and make aluminum plates to cover the holes. One or two transistors can be mounted for each tube removed by this method.

A complete conversion of a twenty-year-old Super-Pro was made using the transistor lineup shown in Table I. The antique receiver cost $30 and the 14 transistors required for the conversion cost about $25. The total cost was about $65, including the cost of a coat of paint. Certainly, for the price, few commercially available amateur receivers could compare with the sensitivity and selectivity of the converted Super-Pro (mechanical stability leaves something to be desired, but it poses no real problem).

For example, at 15 MHz the cw sensitivity, crystal filter off, is approximately 0.4 μV for a 10-dB signal-plus-noise to noise ratio; with the filter in its sharpest position, less than 0.2 μV for 20-dB $S + N/N$. Using a diode detector with a 400-Hz 30-percent-modulated signal for a-m reception, sensitivity for 20-dB $S + N/N$ is approximately 1.2 μV at 15 MHz and less than 2 μV at 8 MHz. Before conversion the sensitivity was of the order of 2 μV for 10- to 20-dB $S + N/N$.

[EDITOR'S NOTE: Extreme care should be used in handling MOSFETs, as the gate-to-channel insulation is easily punctured if the safe gate-to-source voltage is exceeded. Static charges or transient voltages often exceed the safe rating if the dc gate-source circuit is open, as in handling the transistor or inserting it in the socket. Before removing the metal ferrule that short-circuits the transistor leads, wrap a fine bare wire around the leads and ground the wire to the chassis. The leads may then safely be inserted in the socket, after which the shorting wire can be removed. Take similar precautions when removing the transistor from the socket. The power has to be off, of course, to avoid shorting the supply voltage.] QST