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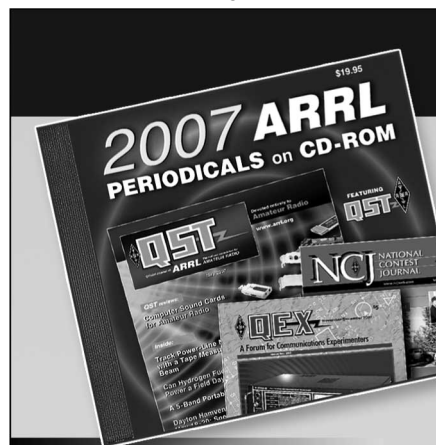
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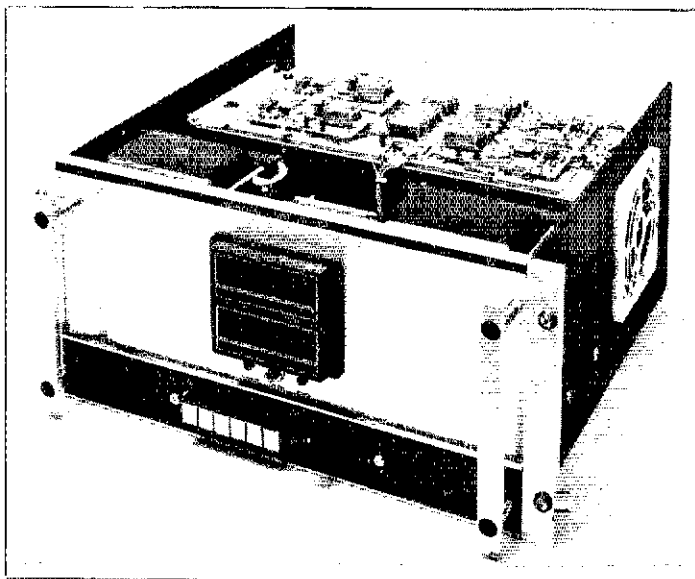
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MOSFET RF Power — An Update

Part 2: The general application information provided in this series offers hard proof that power FETs have graduated beyond infancy. This concluding installment describes filtering methods and other modern amplifier concepts.

By Helge Granberg,* K7ES/OH2ZE



In Part 1 of this article (December 1982 QST), the author described a number of design and performance features for his 2-30 MHz, broadband MOSFET linear amplifier. Part 2 provides a wrap-up and offers a variety of design principles that can be applied to other solid-state power amplifiers.

Output Low-Pass Filters

Chebyshev five-pole, constant-k low-pass filters are used in the amplifier output (Fig. 5). Shunt elements have been added to provide an elliptic function. These elements usually are designed to resonate with the filter inductances at the harmonic or other undesired frequencies. This provides notches that give much higher close-band attenuation than can be obtained from a simple five-pole filter. The filter skirt is also much steeper, but at the cost of degraded far-band attenuation. However, in an application such as this in which the filters are used at a multiplicity of frequencies, they can't be optimized in this respect. The worst case (–35 dB) for the third harmonic (which is of the most concern) is with the low-frequency filters. This probably is caused by the low Q of the inductors.

The total harmonic attenuation at 7

MHz and below is approximately 50 dB or better, which meets the FCC requirement of 50 mW maximum for spurious emissions. The 1.8 to 30 MHz range can't be covered by the six filters without resultant gaps; a minimum of eight filters with sharper cutoff characteristics would be required for continuous coverage.

Filter Construction

Each filter is assembled on a separate pc board of similar layout. Only the component values are different. The most critical parts are the capacitors — often a stumbling block for practical high-power filter design. At these power levels, they must withstand peak rf voltages up to 800 (even higher in the event of a mismatch). The rf-voltage rating of ceramic capacitors is only some 30% of the nominal dc value. Hence, capacitors with ratings of 2000 to 3000 V are required. Also, they must be able to handle rf currents up to several amperes. These filters contain several inexpensive disc-ceramic capacitors in parallel. This provides current capacity and permits capacitor combinations that yield nonstandard values, as needed.

The distance from each filter input or output terminal is 2-1/2 inches to the corresponding terminals of the adjacent filter. This amounts to a distance of 12-1/2 inches from the first to the last

filter.³ Sections of 50-ohm strip line (Z1, Z2) are used to connect the T-R switch and the power amplifier to the filters. These are made of copper-clad pc-board material that is attached to the chassis below the filter boards. The lowest-frequency filter is located nearest to the input and output ends of the line, while the highest-frequency filter is at the far end. Thus, when the filters are switched, the remaining piece of unterminated line causes minimum VSWR in each case. Although the filters were tested individually with the amplifier, L1, L4, L7 and L10 had to be added to restore the filter characteristics in the composite circuit. This was necessary because the mechanical arrangement and the added capacitance from attaching the relay contacts to the 50-ohm lines affected the filters.

Filter-Relay Driver

Each relay field coil is driven by the circuit of Fig. 7. It is basically a programmable BCD-to-decimal decoder. The gates were added to accommodate the manual-switching feature. When the BCD input plug is disconnected, the manual switch is activated automatically. MMH0026 MOS clock drivers (U10-U12)

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³Notes appear on page 33.

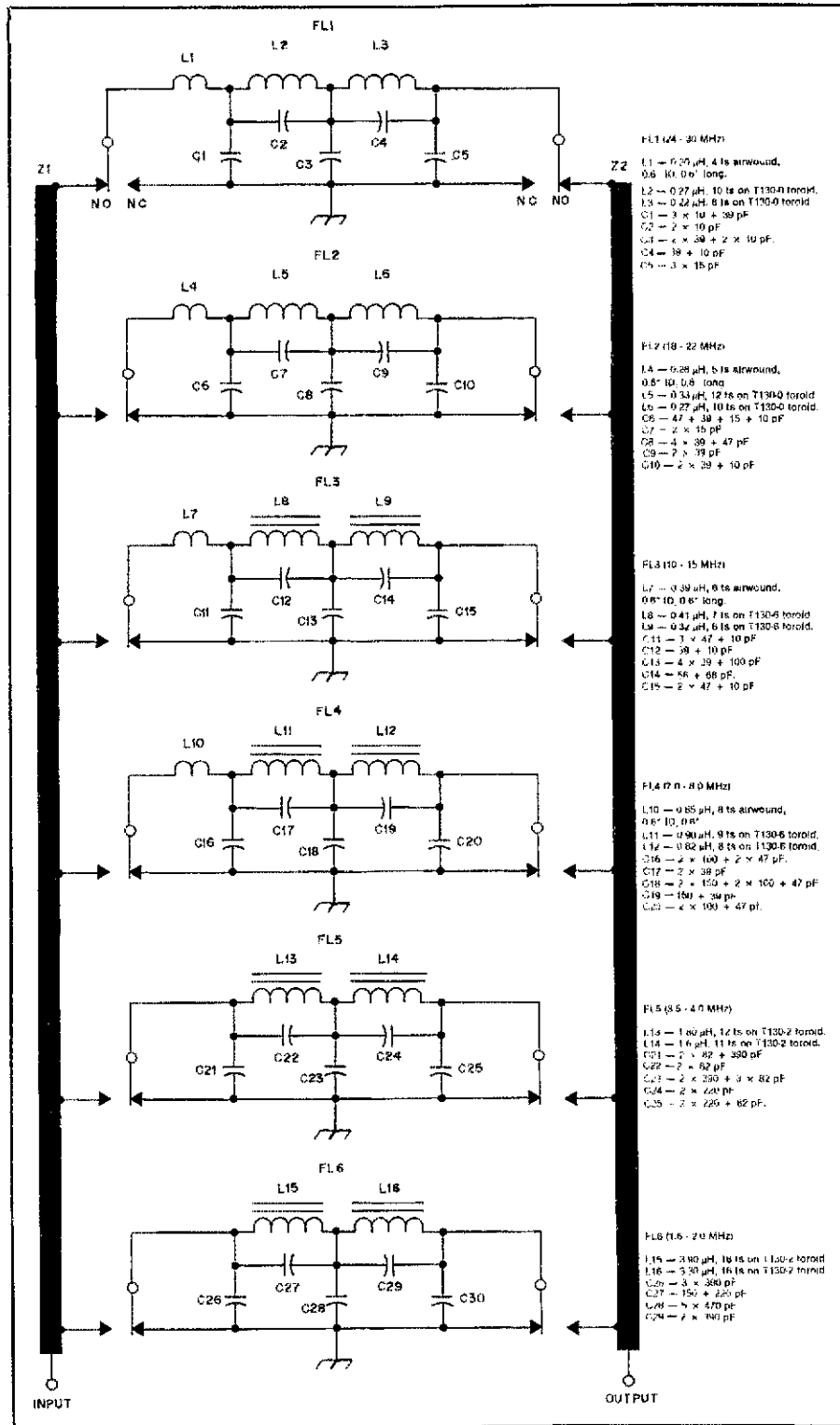


Fig. 5 — Low-pass filter circuit and component values for 1.6-30 MHz operation. Standard capacitor values have been placed in parallel to obtain nonstandard values. Toroid cores are Amidon, Palomar or Micrometals Corp. powdered-iron units. The designator "x" means "times," E.g., 2 x 47 + 10 pF means two 47- and two 10-pF capacitors, all in parallel to provide 114 pF. Wire type for all inductors is no. 14 enameled. Capacitors are RMC 3-kV disc ceramic, except those units that are 390 pF and higher, which are RMC 2-kV units. Relays are Deltrol 20693-83/405 with 12-V coils.

are used because they can be operated directly from a +12-V supply. Also, they have internal clamping diodes for suppressing inductive spikes.

T-R Relay and Timing Circuit

Fig. 8 shows the T-R relay driver and

timing circuit. The input-output timing of the T-R relays must be precise. If the output relay is switched with full rf power, the relay lifetime will be very limited. Thus, the output relay must be switched on before the input relay is. Similarly, the output relay has to be switched off after

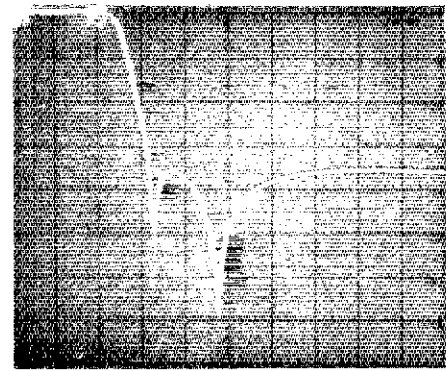


Fig. 6 — Typical response curve of an elliptic function low-pass filter with two resonant shunt elements.

the input one is deactivated. Simple R-C and diode networks are used to generate the delays.

A CMOS hex inverter performs the amplifier pulse-shaping functions. The upper channel, which controls the input relay, delays the leading edge of the keying pulse and shortens it by a few milliseconds. The lower channel controls the output relay, and delays the trailing edge of the keying pulse, which is lengthened from the original as shown in the timing diagram. Both delays are adjustable from 2 to 12 ms by means of R2 and R4.

Other Circuitry

The circuit in Fig. 9 performs the following functions:

- 1) Output VSWR detection.
- 2) Linear alc control.
- 3) Alc shut down.
- 4) Bias switching between standby and operate.
- 5) Bias temperature tracking.

The VSWR reflectometer senses the reflected power caused by load changes (50 ohms nominal).^{6,7} Capacitor C is approximately 1 pF in value and must be capable of handling high rf voltages. It can be made from a piece of coaxial cable, such as RG-58/U, with the braid stripped to a length of 0.4 inch. The section of center conductor can be used as the primary of T1 and for connections to the amplifier output and relay terminal.

The rf meter (normally seen in place of D4) is replaced with a diode for rectifying the rf energy. The resultant voltage is filtered by means of C6 and R31. The level of 0.2-0.3 V for a 50-ohm load. It increases to about 1.5 V for 3:1 VSWR. This voltage is used for the linear alc function and is fed to the alc amplifier, an LM307. Controls R26 and R30 can be set, for example, so that an output VSWR of 2 will have no effect, but a 3:1 condition will reduce the power output by 3 dB or more. The alc shutdown operates also from the dc developed in the VSWR bridge. During a complete mismatch, such as an open load, the instantaneous voltage is greater than 10, thereby saturating the

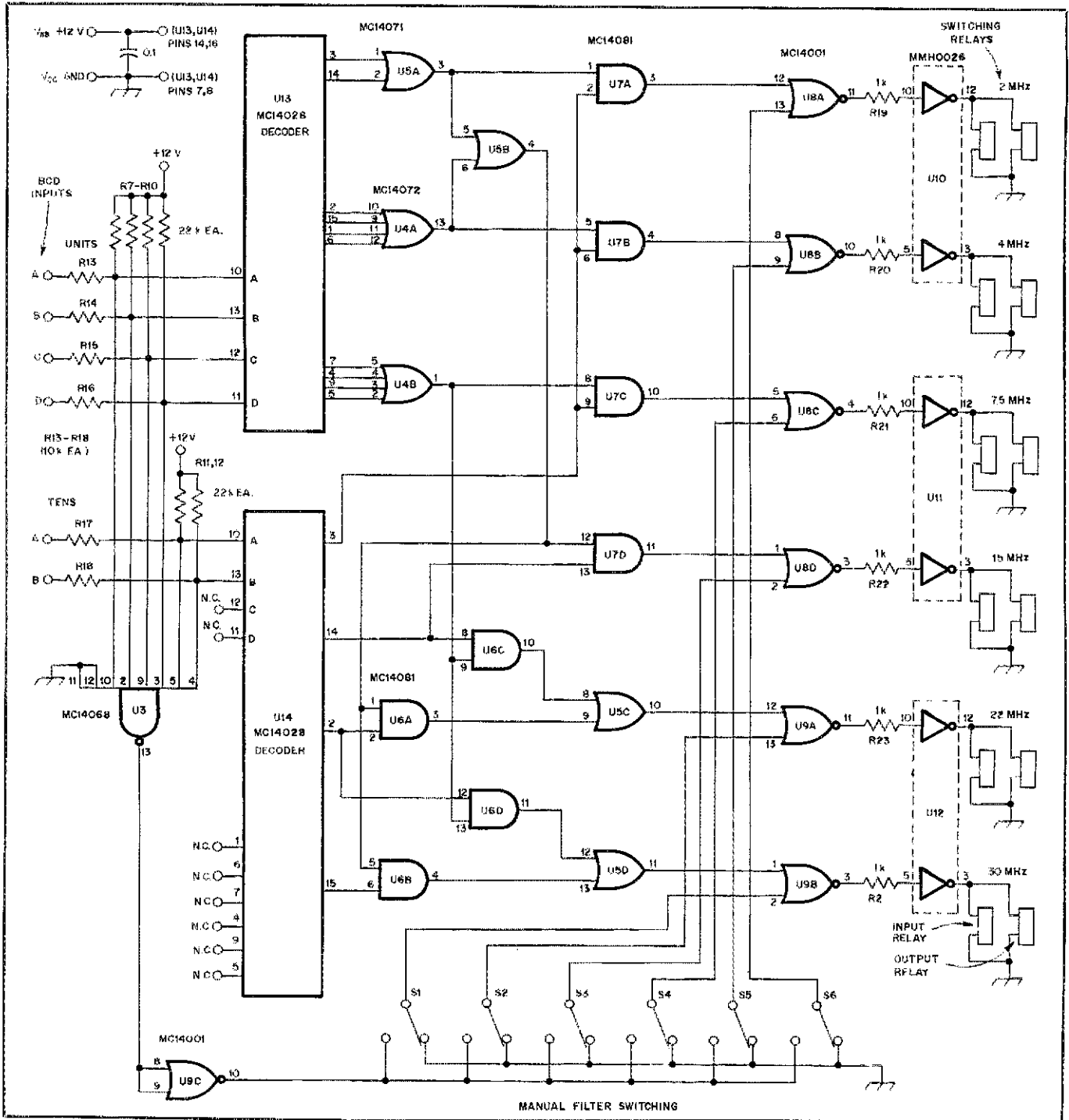


Fig. 7 — Output filter select and drive circuit indicator lights are connected in parallel with the relay coils, which are at the far right of the diagram.

LM307. After the alc loop has reacted and the power output has been reduced by a factor of 10, the voltage settles to 5 or 6 and the alc amplifier remains saturated. This holds the output power at the reduced level.

Automatic bias switching is initiated when a ground to +12-V signal is brought from the T-R relay driver to the same (-) input of the LM307. This overrides the control signal coming from the VSWR sensor and, when positive, turns

the bias completely off. D5 makes this independent of the alc function.

Each of the rf amplifiers (Fig. 4, Part 1) and their associated circuits draw approximately 15 mA of bias current. The combined current is 120 mA, which is too much for the alc amplifier to handle. Therefore, a TIP31 has been added for use as a buffer/driver. Its input voltage is also controlled by a thermistor (R34), which is connected thermally to one of the main heat sinks. R34 controls the idling

current of the power FETs by lowering the bias voltage during periods of elevated temperature, and vice versa. With bipolar transistors, this is normally done with forward-biased diodes, in which the diode voltage drop versus temperature closely follows that of the base-emitter junction. Both types of transistors have a positive temperature coefficient (for a constant bias current or voltage, the idling current increases with temperature). Although the g_m (transconductance) of a MOSFET

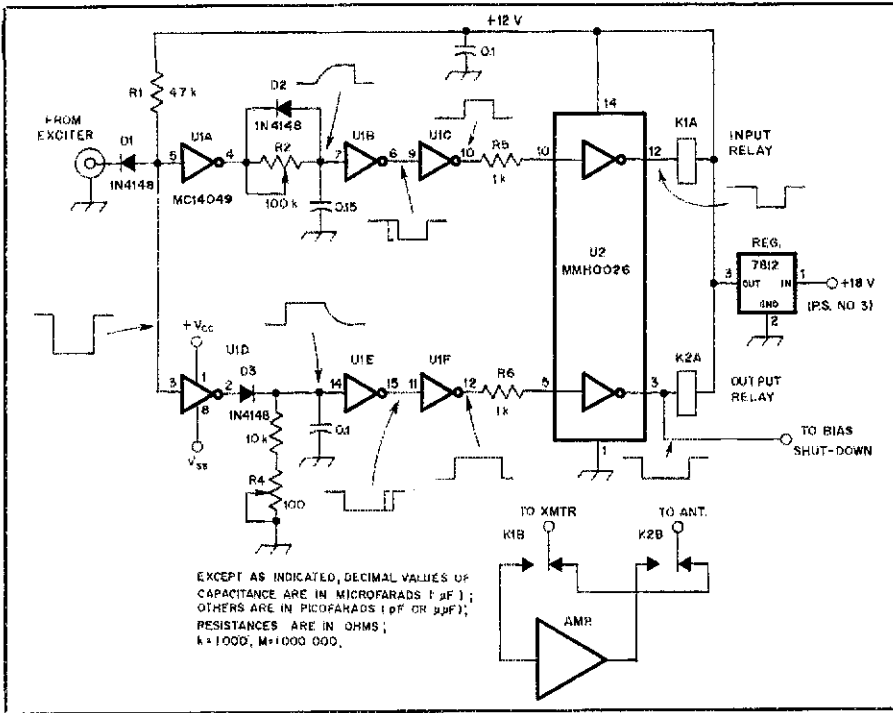


Fig. 8 — T-R switch drive and timing circuit. The approximate wave forms for the input and output functions are shown near the related ICs. Fig. 9 provides details of the relay connections.

decreases under these conditions the gate threshold voltage goes down, and usually has a dominant effect. There is a reversing point at higher drain currents. For the MRF150, this is around 5 A. The exact value depends on the g_{m1} and the initial temperature. This is why power MOSFETs do not go into thermal runaway, provided the dissipation ratings are not exceeded.⁸

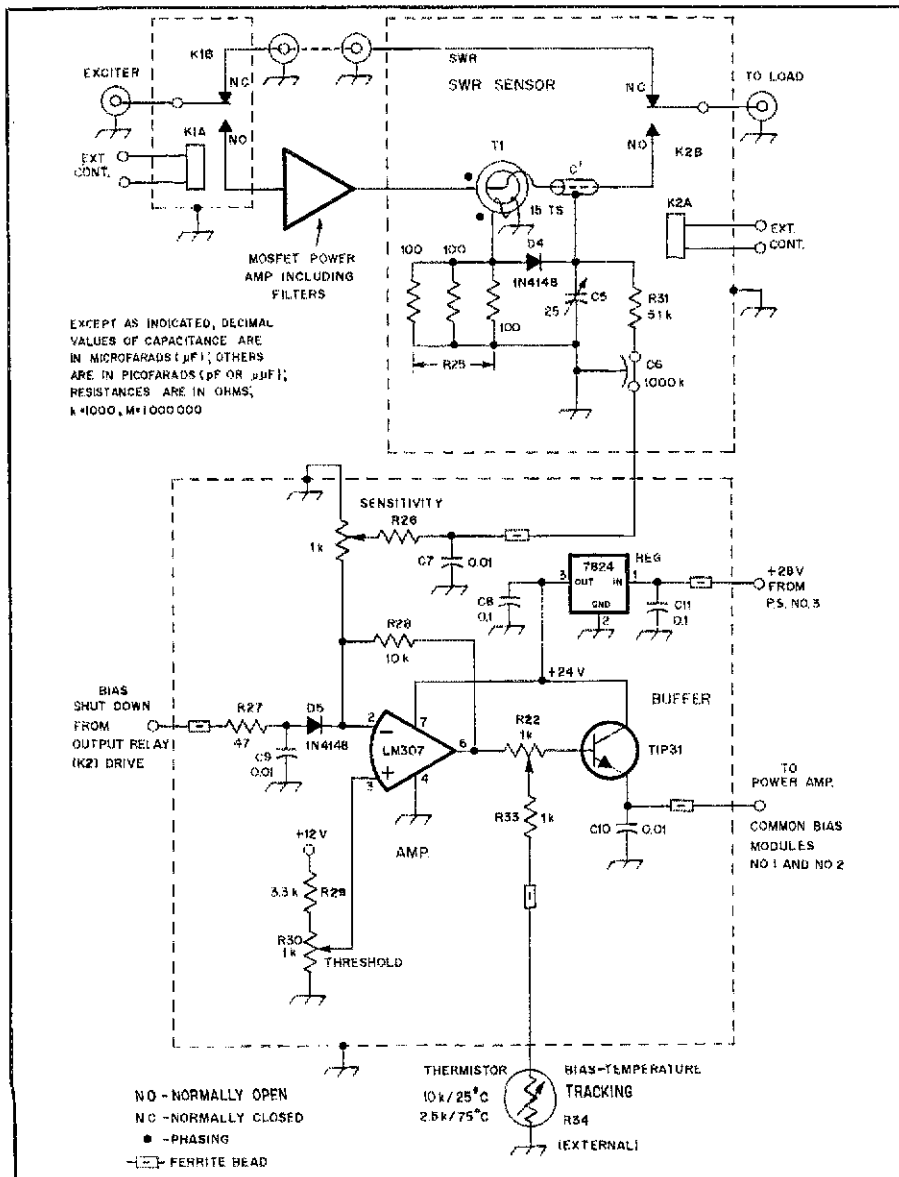
Conclusion

Although solid-state, high-power rf amplifiers are not in competition with vacuum-tube units, an increasing number of them appear on the commercial market regularly. Their feasibility versus output power is a question to be answered, at least until high-voltage rf transistors are available.

Power FETs are high-voltage, low-current devices, and some switching transistors for use up to several hundred volts are now on the market. In rf applications, however, several problems exist. Because of the internal structure of a transistor, rf arcing occurs (internally) easier at high voltages because the impedance levels are high. Transistor packaging techniques must be improved for this reason, and also for thermal considerations. The vertical-channel power FET (VFET) technology is fairly new and will certainly undergo many advances in the years to come.

This amplifier has been field-tested since late 1981, at the author's home. Switching from band to band is an absolute delight. Since no tuning is required, it should be a contest-operator's dream! Thus far, the only failures have been a jammed thermal switch that operates the fans, plus a burned low-pass filter board, caused by a loose piece of solder.

If you haven't worked with power FETs thus far, perhaps it's time you became involved, but maybe on not so grand a scale as is represented by this paper. Certainly, there are many advantages in the use of power FETs over bipolar transistors.



Notes

- ¹mm = in. × 25.4
- ²The Radio Amateur's Handbook, 59th edition (Newington: ARRL, 1982).
- ³W. Orr, Radio Handbook, 18th edition (Indianapolis: Howard W. Sams & Co.).
- ⁴MRF150 data sheet, plus appropriate linear IC and CMOS data sheets.

Fig. 9 — VSWR sensor, aLC and bias circuits. Note ferrite-bead chokes in all aLC input and output lines. They help prevent rf energy from getting into the aLC amplifier.