

## Power FETs as RF Power Amplifiers

How do power FETs compare to bipolar transistors in RF power service? Do they offer advantages not available when using bipolars? What weak points might we expect when working with power FETs? These are common questions in the minds of experimenters who have not used power FETs. We will consider the pros and cons of power FETs in this month's discussion.

### Comparing FETs and BJTs

FET stands for field-effect transistor. BJT is the acronym for a bipolar junction transistor. Outwardly, the two devices look alike, and there are internal similarities. Basically, the BJT has a low input impedance, comparatively speaking. Most RF power amplifiers that use BJTs have an input impedance that may range from three or four ohms to perhaps 15 ohms. This makes input matching to the usual 50-ohm signal source a bit tricky.

FETs, on the other hand, have a

characteristically high input impedance which is typically one megohm or greater. Also, a power FET has its input terminal (gate) insulated from the drain-source junction, whereas the input terminal of a BJT (base) is part of the collector-emitter junction. In terms of the input impedance, we may consider a power FET as similar to a triode vacuum tube.

The output impedance of BJTs and power FETs are similar. Both exhibit a low output impedance. This is determined by the collector voltage and the output power. In both situations, the impedance may be calculated by  $Z \text{ (ohms)} = V_{cc}^2$  divided by  $2P_o$  when working with BJTs, where  $V_{cc}$  is the collector voltage and  $P_o$  is the design output power.

For power FETs  $Z \text{ (ohms)} = V_{dd}^2$  divided by  $2P_o$ , where  $V_{dd}$  is the dc drain voltage. Thus, if a power FET is called upon to deliver 10 watts of output power and the  $V_{dd}$  is +24 V, the output impedance is 28.8 ohms.

The lower the collector or drain voltage, the lower the output impedance. For example, a BJT that delivers 10 watts of output power and has a +12-V supply will have an output impedance of only 7.2 ohms. Once again, this tends to make impedance matching to a 50-ohm load a critical proposition, but it can be done.

### FET high points

Power FETs are relatively immune to the self-destructive phenomenon known as "thermal runaway," which does affect BJTs. Also, FETs generate cleaner output waveforms (reduced harmonic current) than is true of BJTs. IMD (intermodulation distortion) products are of lower amplitude in FETs.

The FET input and output capacitances change very little versus operating frequency and voltage changes. This makes input and output matching-network design simpler than it is for BJTs. The feedback networks for broadband FET amplifiers are easier to design for this same reason.

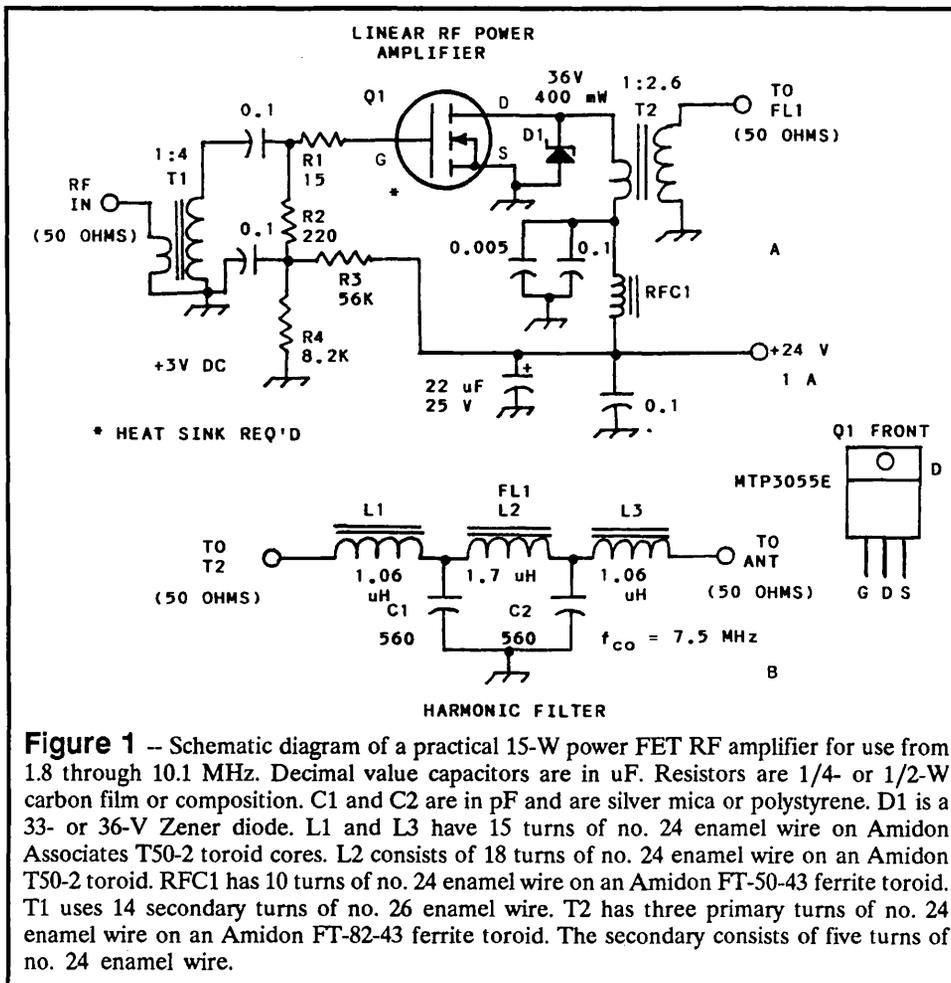
### FET low points

Power FETs are more fragile, respective to mistreatment, than are BJTs. The gate insulation is very thin and can be punctured instantly by excessive gate voltage. Excessive gate current can also damage the thin layer of metal oxide gate insulation. In a like manner, the drain-source junction can be short circuited quickly from excessive drain-source voltage peaks or spikes.

Power FETs are inherently good devices from dc through the VHF spectrum, owing to their internal structure. The smaller FETs, in particular, if they do not contain built-in protective Zener diodes, will often perform well up to 175 MHz.

This depends in part upon the FET RDs (on) rating, which defines the internal drain-source resistance when the FET is fully turned on or in full conduction. The higher the RDs rating in ohms, the poorer the upper frequency performance. The FET's potential for operating well at VHF makes it prone to VHF parasitic oscillation, and this is another problem area for the designer. More on this later.

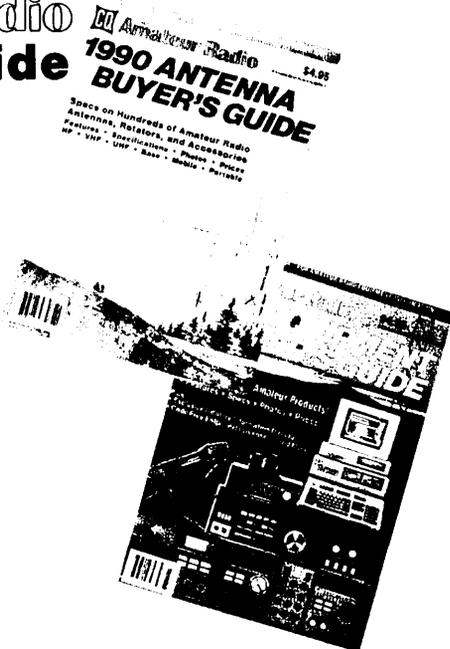
Although it may not represent a low point for FET performance, these devices work best at +24 V or greater. The FET efficiency is very poor at +12 V, even though useful power output can be had.



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## Operating class

Power FETs, BJTs and vacuum tubes may be operated in the class A, AB, B and C modes by biasing the devices accordingly. Positive voltage (forward bias) is applied to the BJT base or the FET gate to cause the transistor to draw a resting or quiescent collector or drain current. The amount of current determines the operating class. Class C operation is satisfactory for CW and FM signal amplification. Linear operation (class A, AB or B) is necessary if we are to amplify AM or SSB signal energy. This minimizes distortion of the output waveform (reduced IMD products).

## A practical FET RF amplifier

Figure 1 contains the circuit for a class AB linear RF power amplifier that delivers 15 watts of output power in the MF and HF spectrum. R2 determines the amplifier input impedance, which is 220 ohms in this example. This makes it practical to use a 1:4 impedance ratio broadband transformer (T1) for matching the amplifier to the 50-ohm driving source.

This resistor negates the otherwise high input impedance of the FET. R1 serves as a VHF parasitic suppressor by deQing this part of the circuit. D1 may be added to work as a peak RF and dc voltage clamp to protect the transistor from excessive voltage peaks. Note:

Some power FETs, such as the IRF511, have this device built into the transistor.

T2 is another broadband matching transformer. It matches the 19.2-ohm drain impedance to a 50-ohm load (FL1). RFC1 and the associated bypass capacitors above and below it function as an RF decoupling network to aid amplifier stability. Bypassing is effective over a wide frequency range because of the different values of capacitance used.

A resistive divider (R3 and R4) reduces the supply voltage to +3 to produce gate bias for linear operation. This simple network is adequate because an FET gate draws only microamperes of dc current. Bias regulation is not necessary.

The maximum peak-peak gate voltage for Q1 should not exceed approximately 30. Excessive driving power will cause these limits to be exceeded, and this could destroy Q1. A pair of back-to-back 15-V, 400-mW Zener diodes may be bridged from the Q1 gate to ground for use as a gate-protection clamp.

Figure 1B shows a 5-element low-pass harmonic filter for use between the amplifier and the antenna. This filter ensures that all spurious output energy is 40 dB or greater below peak output power, which is an FCC requirement. FL1 component values are listed for 40-meter operation. The correct values for C1, C2, L1, L2 and L3, for other bands of operation, may be obtained easily from the normalized filter tables presented in *The ARRL Handbook*.

A heat sink is necessary for the Figure 1A amplifier. It should be the extruded-aluminum type with fins. Minimum size is 3 X 3 inches with a height of at least 0.75 inch. Use a thin layer of heat-sink compound between the transistor body and the heat sink.

## Some final thoughts

Maximum RF driving power for this amplifier is one watt. Typically, full output can be obtained with 0.5-watt of driving power. This equates to an amplifier gain of roughly 15 dB.

The Motorola MTP3055E FET specified for Q1 is not designed for RF service. It is a switching transistor, but works very well from 1.8 to at least 10 MHz. These transistors are inexpensive, and hence my choice of a switching device. The IRF511 may be used as a substitute.

Many other plastic FET switching devices are also suitable as RF amplifiers. Don't be afraid to experiment. FETs that are designed expressly for RF power amplification are very expensive. I don't recommend them for the experimenter who lacks design experience.

Class C operation may be employed by removing R3 and R4, then grounding the bottom of R2. This will require slightly more RF driving power in order to obtain 15 watts of output power.

