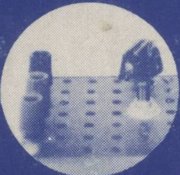
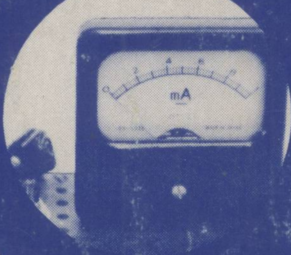
RADIO TRANSMITTER

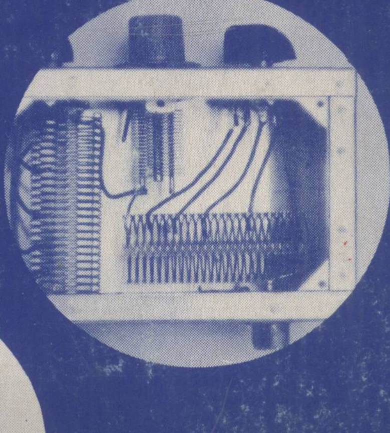
PRINCIPLES and PROJECTS

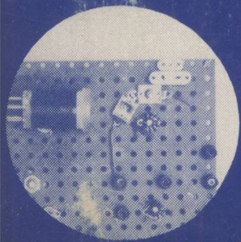


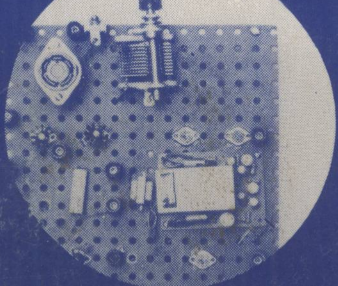
by
EDWARD
M. NOLL

W3FQJ









Radio Transmitter
PRINCIPLES and PROJECTS

by Edward M. Noll, W3FQJ

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PREFACE

The explanations of principles and projects in this book are intended for both students and professional technicians. Each chapter begins with basic principles and advances to more detailed information. The projects are based on the basic principles and are designed to further the reader's understanding through actual experience.

The first three chapters contain information on electron devices—the FET, bipolar transistor, and the vacuum tube. Various modes of modulation—cw, a-m, f-m, dsb, and ssb—are discussed in other sections. Chapter 4 describes hybrid transmitter circuits using tubes and transistors. Double-sideband and single-sideband generation and circuits are included in Chapter 5. There is a chapter on linear amplifiers and mixers; another explains integrated circuits. The final three chapters detail vhf circuits, frequency modulation, and transmitter testing.

The radio transmitter projects are all low-power circuits that can serve as laboratory experiments in schools. The radio amateur will gain practical experience with all types of circuits and systems. It is hoped that the radio technician will find this book to be a helpful guide to modern transmitter principles, ideas, circuits, and techniques.

EDWARD M. NOLL, W3FQJ

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CHAPTER 1

FET CW/A-M Transmitter Circuits

"Radio Transmitter Principles and Projects" has been written for the beginner, the oldtimer, and the experienced technician. Its approach can be summed up as "learn-and-do." Principles are detailed and followed by construction projects that firm your knowledge of transmitter circuit operation. In the early fundamental chapters the projects are of step-by-step detail and include a series of suggested experimental procedures to follow which teach the underlying principles. The coverage provides an excellent introduction to solid-state and combined solid-state, vacuum-tube technology.

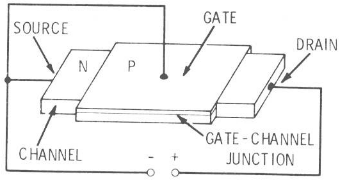
In the first three chapters the basic electron devices (FET, bipolar transistor, and vacuum tube) are covered. First you learn the principle of the device and then the fundamentals of the radio-frequency circuit with which the device can be associated. Then you will learn how the device can be amplitude-modulated. All sorts of devices in addition to the basic three are covered such as diode, voltage-variable capacitor diode, linear integrated circuits, digital integrated circuits, etc. Oscillators and all classes of amplifier operation A, AB, B, and C are covered. The transmitters include all modes of modulation, cw, a-m, dsb, ssb, and f-m.

The projects include small test units on up to complete transmitters that serve well as laboratory experiments or as actual parts of an amateur radio station. Power levels range from QRPP to QRP (very low power to low power) and on up to a maximum of about 50 watts.

In the early fundamental chapters the projects are in the form of experiments that follow along with the text. Even though you do not perform the experiments, read right along with the copy, because the experiments are an inherent part of the chapter continuity. Performing the experiments, however, gives you that extra and very valuable practical experience with new devices and circuits.

FIELD-EFFECT TRANSISTOR

A field-effect transistor (FET) is a three-element device consisting of source, gate, and drain (Fig. 1-1). The source and drain elements



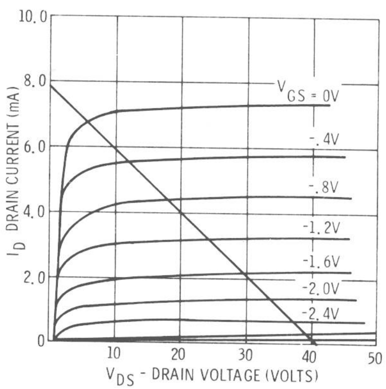
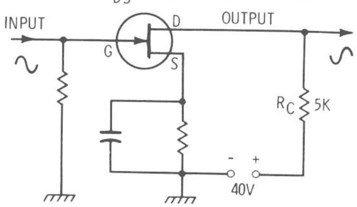


Fig. 1-1. Drawing of basic field-effect transistor.

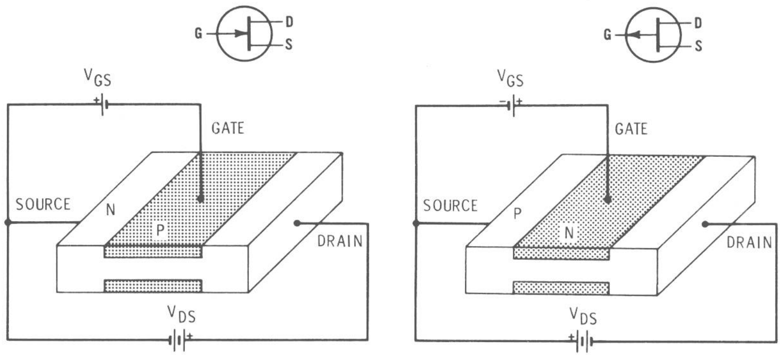


are positioned at the ends of a continuous semiconductor channel. The charge motion along the channel from source to drain depends on the conductivity of that channel. Conductivity is regulated by a third element, the gate, which surrounds all or part of the channel. A single semiconductor junction is present at the boundary between the gate and the channel. Normally this junction is reverse-biased just as the grid of a vacuum tube is biased negatively.

The gate actually has a capacitive influence on the channel. This capacitive effect is such that a charge depletion area extends into the channel. The amount of reverse biasing of the gate determines the extent of the depletion activity and therefore the conductivity of the channel. In turn, the conductivity of the channel determines the charge motion (current) between source and drain.

As the gate reverse bias is increased, the depletion area increases and lowers the conductance of the channel, thus increasing the channel resistance or decreasing the channel conductance. As a result the channel and output drain currents decrease. If the reverse-bias voltage is made to vary, there results a substantial change in the drain current. This substantial drain-current variation in the common-source circuit of Fig. 1-1 produces a substantial voltage variation across the output. Since the drain-voltage variation is greater than gate-voltage variation, the common-source stage has voltage gain.

A typical family of curves is also shown in Fig. 1-1, along with a load line. Note how similar the set of curves is to those of a pentode



(A) N-channel. (B) P-channel.

Fig. 1-2. N- and P-channel FETs.

vacuum tube. The lower the gate bias is, the greater is the drain current. Also over a substantial voltage range the drain current remains essentially constant for a given gate bias as the drain voltage is increased. This is characteristic of a high-resistance device. In fact, the input and output resistances of a field-effect transistor are high like those of a vacuum tube and are unlike the low resistances at the input and output of a conventional bipolar transistor. The field-effect transistor in simple circuits is less prone to distortion and the generation of spurious signal components, compared to a bipolar transistor.

There are two fundamental types of junction field-effect transistors, those with a p-channel and those with an n-channel (Fig. 1-2). An n-channel has a charge motion determined by free electrons. The gate which surrounds an n-channel is a p-type semiconductor material with its electric charge motion determined by free positive charges, or holes. The second type uses a p-type channel and an n-type gate. The only difference is the polarity of the biasing. Note that the drain of an n-channel type is positive with a negative voltage required at the gate to establish reverse-biasing of the junction. Oppositely the p-channel type operates with a negative drain voltage. In this case a positive bias is applied to the gate to reverse-bias the junction.

RF AMPLIFIER

A typical FET class-B or class-C rf amplifier is shown in Fig. 1-3. External bias can be used. Biasing according to class of operation is shown in the transfer characteristic. For class-A operation the biasing is at the center of the linear portion of the transfer curve. To operate the amplifier class B it is necessary that the level of external bias match the cutoff bias of the transistor. A class-C stage is, of course, biased beyond cutoff.

The input impedance of a FET rf amplifier can be kept at its highest by making certain that the peak of the positive alternation of the input signal does not extend to the near-zero bias level that results in gate current. However, for more convenient and efficient operation and a somewhat lower input impedance, the stage may be operated in such a manner that the gate current is drawn at the peak of the positive alternation. In such an arrangement one can use gate current to establish the required class-B or class-C biasing

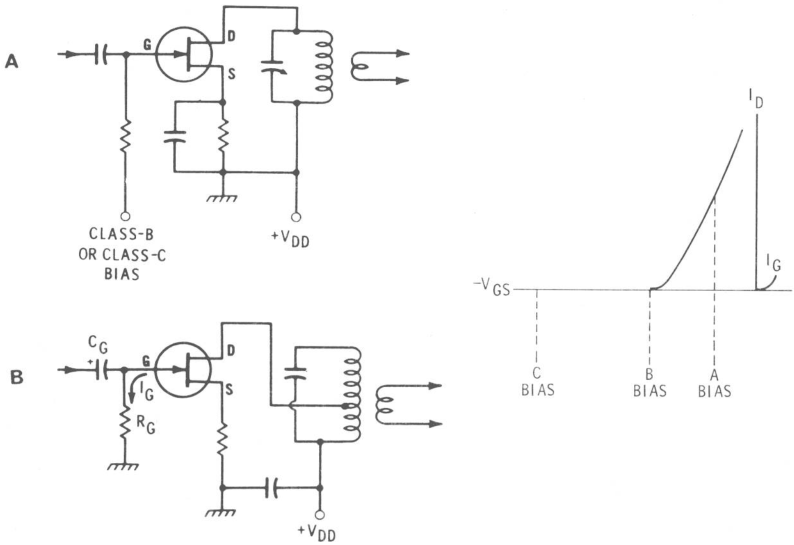


Fig. 1-3. FET class-B and class-C amplifiers.

using the circuit arrangement of Fig. 1-3B. The direction of the gate current is such that a negative bias is developed on the gate capacitor. With a proper time constant this capacitor charge remains constant and serves as the dc gate bias for the stage. As mentioned, the input impedance is now lower, and somewhat more input power is required.

The field-effect class-C amplifier is similar to a vacuum-tube stage in still another way. When the rf excitation is removed from its input, the drain current rises just as the plate current of a similarly designed vacuum-tube stage. It is advisable to use a protective source resistor which limits the drain current to a safe value in case rf excitation is lost. In vacuum-tube practice one often uses a cathode resistor as a safety device.

Approximate class-C waveforms are shown in Fig. 1-4. During the portion of the input wave that causes drain current there is a strong but short-duration burst of drain current. This burst of current contributes power to the output resonant circuit. In fact, at this time the tank capacitor is charged to a negative peak and the drain voltage is at minimum value.

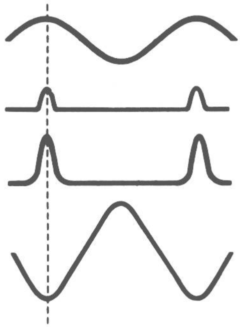


Fig. 1-4. FET class-C waveforms.

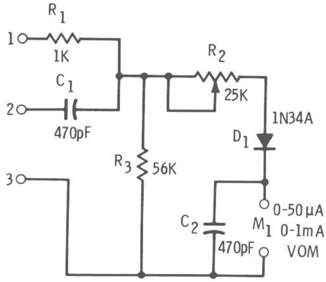
It is important to recognize that with a strong input signal the peak drain current rises from zero to a high peak value. Consequently there can be a substantial change in drain voltage and the power delivered to the drain resonant circuit is much greater than the signal power level delivered to the gate of the transistor. The energy delivered to the tank circuit is stretched out because of the energy-storage capability. As a result a sinusoidal rf voltage is developed across the tuned circuit.

The gate current is present only for a very short interval of time that coincides with the positive peak of the input voltage. Just enough gate current is drawn to charge the bias capacitor.

PROJECT 1: OUTPUT INDICATOR

Before starting construction of your first transmitter circuits, you should build a small piece of test equipment that is helpful in working with solid-state rf amplifiers. This output indicator is shown schematically in Fig. 1-5. It is nothing more than a simple diode detector circuit which develops a dc output voltage that corresponds to the amplitude of an rf signal. Useful readings are obtained for rf power levels considerably lower than 100 mW. A potentiometer is included, and permits the measurement of higher power levels. When measuring across a low-impedance source, connect the signal to be evaluated between inputs 1 and 3. In fact, the indicator can be left connected across the transmitter output to a low-impedance antenna when the transmitter is in operation and feeding power to the antenna.

If the transmitter is to be terminated in a specific impedance, that value can be connected between terminals 1 and 3. For example,



C_1,C_2	470-pF capacitors	R_1	1K ½-watt resistor
D_1	1N34A diode	R_2	25K potentiometer
M_1	Current meter, 0-50 μA or 0-1 mA		5 binding posts

Fig. 1-5. Rf indicator.

if the transmitter is to supply power to a 50-ohm load, one can connect such a 50-ohm resistive termination (of proper power-handling capability) across terminals 1 and 3 and the transmitter will see a proper matched load.

If the signal is to be evaluated at a high-impedance point, use terminals 2 and 3. The presence of the capacitor also permits ob-

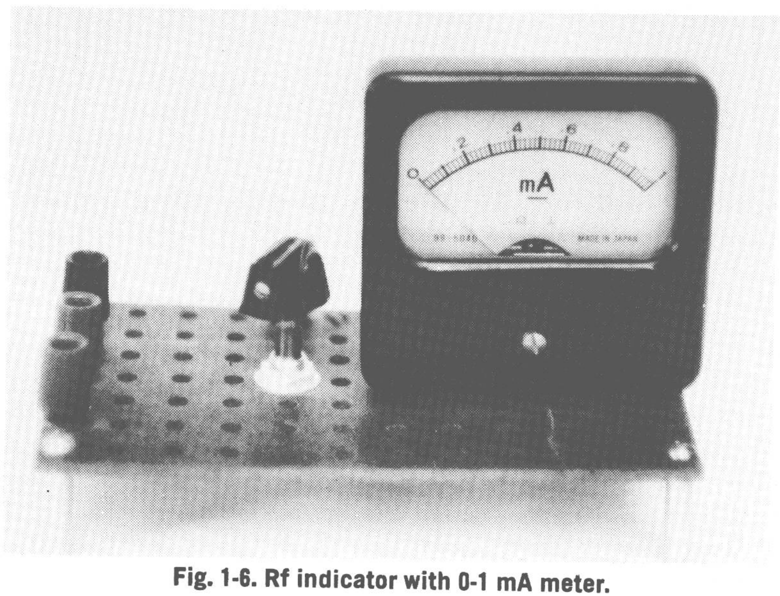


Fig. 1-6. Rf indicator with 0-1 mA meter.

servation where there is a dc as well as an rf component. The capacitor blocks the dc voltage from the detector circuit.

The indicator can be 0 to 1 milliammeter or one with an even higher sensitivity. A volt-ohm-milliammeter (vom) can also be used and provides some additional versatility because of a choice of current scales. The unit can be mounted on a small 3″ × 6″ *masonite* pegboard. The five binding posts provide convenience in use. Such an arrangement with a mounted milliammeter is shown in Fig. 1-6.

PROJECT 2: FET CRYSTAL OSCILLATORS

Most projects of this chapter will be built on the single pegboard arrangement shown in Fig. 1-7. First mount four transistor sockets

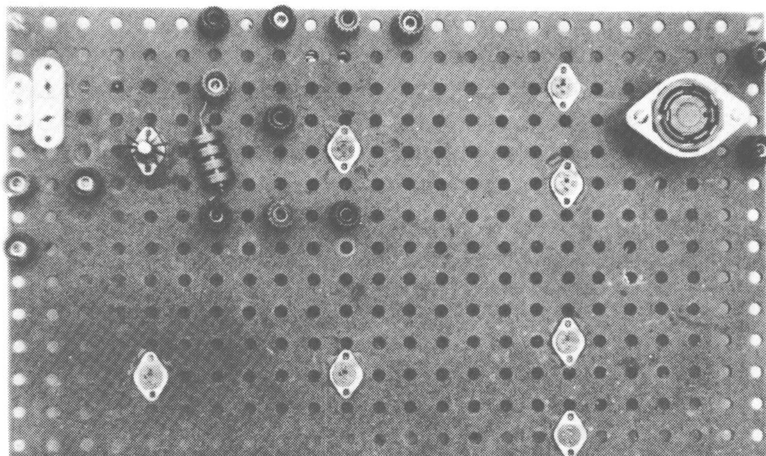
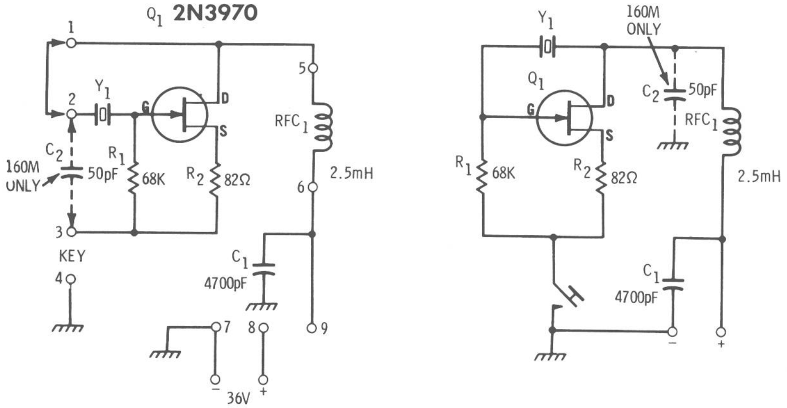


Fig. 1-7. Basic arrangement of pegboard for oscillator circuits.

as per the top half of arrangement. Experiments on crystal oscillator circuits will be made in the area at the top left. A FET and its heat sink are shown along with two crystal sockets to accommodate the two common size crystal plugs. Various binding posts have been mounted in positions that permit ease in making circuit changes. A five-prong tube socket has been mounted at the top right. In later projects, plug-in coils will be used in the tube socket.

20-40-80-160 Pierce Oscillator

Assemble the circuit of Fig. 1-8. Note that nine binding posts are used. A Pierce crystal oscillator circuit is formed by connecting a



C_1	4700-pF disc capacitor	RFC	2.5-mH rf choke
C_2	220-pF disc capacitor		Miscellaneous Parts
Q_1,Q_2	2N3970 transistors	Pegboard	
R_1	68K ½-watt resistor	Transistor sockets	
R_2	82-ohm ½-watt resistor	Binding posts	

Fig. 1-8. Pierce crystal oscillators.

jumper between binding posts 1 and 2 and a 2.5-mH radio-frequency choke between posts 5 and 6.

Drain current can be measured by inserting a 0-100 milliammeter between terminals 8 and 9. When measurements are not being made a jumper can be inserted between binding posts 8 and 9.

The output of the crystal oscillator can be evaluated with the output indicator. Connect binding post 5 to binding post 2 of the indicator and binding post 3 of the indicator to one of the common (ground) binding posts of the oscillator (Fig. 1-9).

Operation—Wire the oscillator carefully to set up the circuit of Fig. 1-8B. Plug in a 40- or 80-meter crystal. Close the key or connect a jumper between posts 3 and 4 to turn on the oscillator. Note the drain current and the output indicator reading on 40 and 80 meters. Tune in the signal on your receiver.

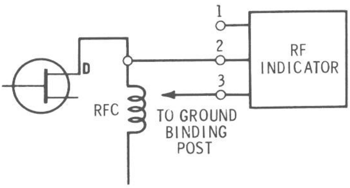


Fig. 1-9. Connection of the output indicator.

Insert a 160-meter crystal. The oscillator may be sluggish in starting on this frequency. A greater capacitive load on the drain output circuit will overcome the problem. Connect approximately a 50-pF capacitor from drain to common whenever operating on 160. One way of doing this is to connect the capacitor to binding post 3 or 4 from either binding post 1 or 2. It can be removed when operating on other bands.

Try a 20-meter crystal in the oscillator. Output reading will be about the same on all bands. Typical output readings fall between 0.35 and 0.5 (maximum sensitivity) milliamperes. Drain current falls to between 25 and 30 milliamperes and somewhat higher on 160 meters.

Drive Reading—Connect the gate circuit of what will be the second stage of the transmitter. This circuit consists of capacitor C_2 and resistors R_3, R_4, and R_5 (Fig. 1-10). The rf drive into this

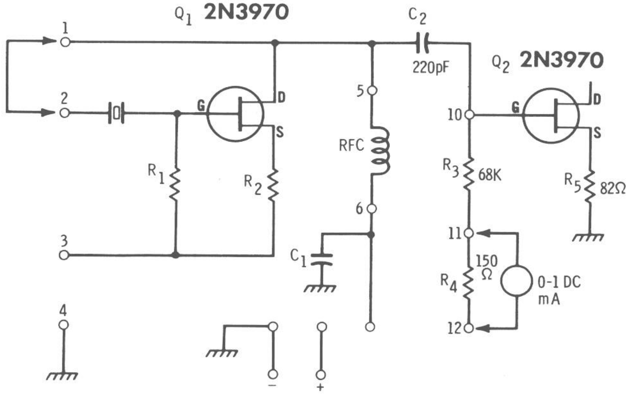


Fig. 1-10. Measurement of drive to next stage using gate current.

stage will cause a flow of gate-circuit charges (gate current). This is a rectified component and a dc meter connected across resistor R_4 will give a relative indication of the rf drive. The dc is of course a