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FETS FOR CONSUMER ELECTRONICS—A PROGRESS REPORT

Introductory comments made by Thomas S. Edwards, Siliconix Incorporated, panel member on Field-Effect Transistors at the IEEE Spring Conference on Broadcast & TV Receivers in Chicago, Illinois, June 15, 1965.

In the transition from tubes to bipolar transistors, circuit engineers were required to convert from voltage node to current node design. The present trend toward FETs requires conversion back to voltage-node design. Those engineers who never changed to bipolar devices will have an easy time designing with FETs. Those who learned to design with transistors like I did had better dust off Millman & Taub's "Pulse & Digital Circuits", Seely's "Electron Tube Circuits," and Valley & Wallman's "Vacuum Tube Amplifiers", and go to work.

In general, FETs act like pentode vacuum tubes and may be used to increase circuit impedance and Q, increase current sensitivity, and reduce component count with equal or improved performance. Three factors lead us here today to discuss FETs for commercial applications:

1. Improvements in physics and technology make devices possible with predictable performance at necessarily low prices.
2. Certain circuits crave FET characteristics to perform functions better than bipolar transistors.
3. The rapid increase in the number of FET manufacturers virtually assures the circuit designer of multiple sources, thus expanding the available market.

Device technology has improved similarly to bipolar transistors, i.e., more efficient structures improve performance continuously. Figure 1 shows the improvement in maximum frequency of oscillation for FETs announced by Siliconix over the past three years.

The 2N2606 series (2N2606-9) announced two and one-half years ago has a f_{co} of less than 100 mc. In early 1964, the 2N3376-87 series was announced, having f_{co} from 100-200 mc. Today, with the 3N89 tetrode and developmental MOS* units, f_{co} ranges from 200-1000 mc.

* Metal-Oxide-Semiconductor

The MOS FET improves the performance of some circuits compared to junction FETs, thus further expands the scope of FET applications. Figure 2 is a comparison of major applications in which MOS and junction devices will each have long-term advantages.

MOS FETS

Advantages

Higher g_{fs}/C_{is} and g_{fs}/C_{rs} ratios are possible for given masking tolerances, resulting in better high-frequency performance.

Gate current is typically 3-to-4 decades lower than comparable g_{fs} junction devices, thus making the MOS device desirable for electrometer applications. The gate never looks like a forward biased diode.

Disadvantages

Exceeding the rated gate breakdown voltage may result in permanent damage. (Gate looks like a silicon-oxide capacitor.) Conversely, a junction gate can withstand 40-50 ma of current without damage. Extreme care must be exercised in handling MOS units to prevent gate damage.

Gain determining parameters (g_{fs}, I_{DSS}, and V_P) are surface dependent; they are bulk-material dependent in junction devices. The result: d-c characteristics and transconductances will never be as stable with time, temperature, and voltage as junction FETs. It's like comparing the relative stability of I_{CBO} and V_{BE} on bipolar transistors; V_{BE} is a bulk parameter and is always statistically more stable than I_{CBO} on a well-made bipolar device.

JUNCTION FETS

Advantages

Junction FETs have much lower low-frequency noise and stable gain determining parameters due to the bulk diffused channel. MOS devices have a surface channel which is less stable.

Controllable and repeatable I_D, V_{GS}, and g_{fs} variation with temperature make the junction device far more desirable for accurate timers, differential and single-ended d-c amplifiers, and low-noise audio amplifiers.

Availability of tetrode structure having dual gate control permits 40-60 db AGC control in narrow-band amplifiers with virtually no detuning.

The very rugged gate looks like a Zener diode and can withstand heavy overload without destruction.

Junction FET production has a three-year headstart on MOS units, resulting in lower cost, proven reliability, MIL-Spec parts, and multiple suppliers of the same type number.

Disadvantages

Higher and temperature dependent gate current.

Only normally ON types are available.

Lower gain-bandwidth product for equivalent g_{fs} means lower f_{co}.

The choice of junction vs MOS devices becomes very applications-cost-reliability dependent. Recommendations shown in Fig. 2 will generally hold true and save time for the designer. Consumer circuits in which FETs will rapidly pay their own way via a desirable cost-performance tradeoff include:

1. Electronic timers, temperature compensated if necessary, and insensitive to line voltage transients. Two circuits from a recent Application Note* are shown in Figs. 3 and 4.
2. Phono and microphone preamplifiers of various complexity such as those in Figs. 5, 6, and 7. The two-transistor circuit shown in Fig. 5 uses a FET to replace two or three bipolar transistors. One more stage would be required to add volume and tone controls. Audio amplifiers driven from high impedance transducers are the most economical consumer FET application today. Devices for such circuits can be made available in production quantities well under $1.
3. Automobile radios which suffer from poor input-overload response and selectivity. MOS FETs or tetrode junction FETs make ideal "front end" and i-f amplifiers to solve the problem. A 455 kc i-f amplifier with 40-50 db AGC capability and virtually no detuning is shown in Fig. 8. Its gain control curve is shown in Fig. 9.
4. Extending this idea to other communications bands, Figs. 10 and 11 show a 44 mc i-f amplifier with AGC using the 3N89 tetrode junction FET. This type of circuit could be most useful in transistorized TV i-f stages. Using bipolar transistors, i-f stages must have a very broad band. With the tetrode FET, narrow-band stagger-tuned stages may be used with AGC applied to all stages.
5. Video preamplifiers with 25-35 mc bandwidth can be as simple as that shown in Fig. 12. (Fig. 13 shows response curves.) Use this

* "FETs in Solid-State Timers", Siliconix Application Note, May 1965.

circuit as a preamplifier for video tape recorders.

6. Transistorized FM receiver "front ends" suffer from severe overload intermodulation distortion more than AM receivers. The neutralized 100 mc i-f stage in Fig. 14 demonstrates circuit performance possible with a developmental h-f MOS FET.
7. The 160-mc oscillator in Fig. 15 demonstrates performance of the 3N89 junction tetrode at 80% of its calculated f_{co}. Usable power is dependent on I_{DSS} of the FET and V_{DS} as shown in Fig. 16.

FET prices are rapidly entering the consumer products range. With present-day technology, $0.50 to $1.00 prices can be made available for very large quantity orders on certain devices. Even small quantity prices (100-299) are under $2.00 today on some established units. An average of Siliconix published prices over the past two and one-half years is shown in Fig. 17. Over a 4-to-1 reduction during a period when competition was minimal testifies to the effects of increasing production.

To make the $0.25 to $0.50 device possible, the FET manufacturer must have customer committments. When? Probably 1966 for the $0.75 to $1.00 unit and 1967 for the $0.25 to $0.50 unit.

Design work must start NOW to reach these goals.

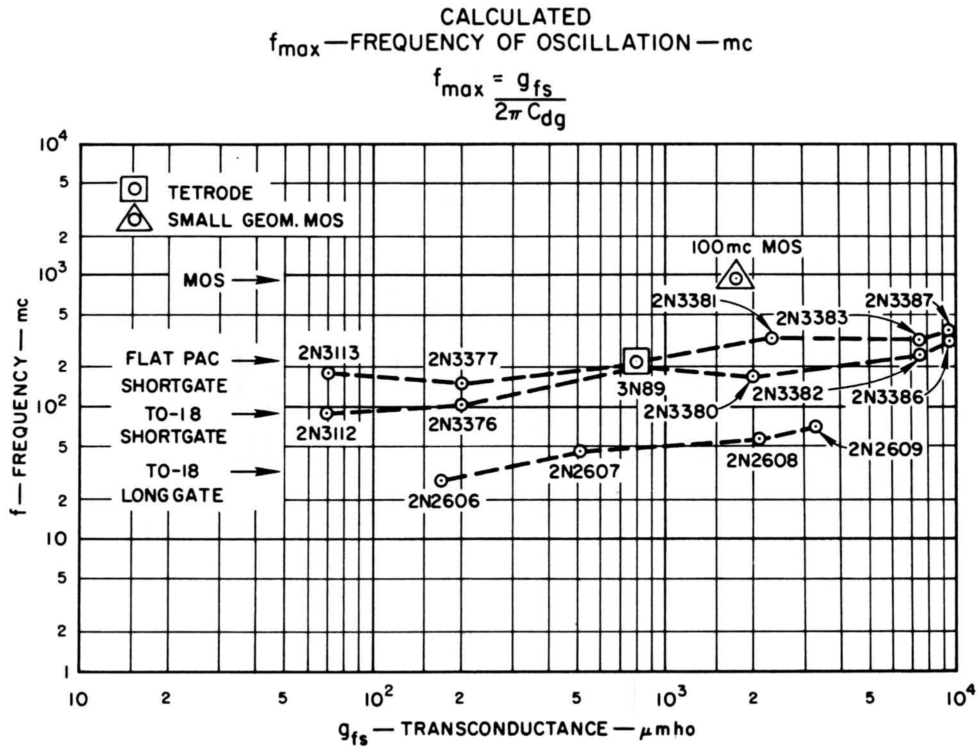


Figure 1

MOS AND JUNCTION FET APPLICATIONS

MOS

Direct-Coupled Switching Circuits
Very High $R_{D(OFF)}$ Choppers
Electrometers
Triode High-Frequency Amplifiers
Sample & Hold Applications

JUNCTION

Stable d-c Amplifiers
Controlled and Repeatable Parameter Temperature Coefficient Applications
Differential Pairs
Low-Frequency Low-Noise Amplifiers
Tetrode Structures for AGC High-Frequency Amplifiers
Stable Voltage-Variable Resistor Applications

Figure 2

0.1 - 50 SECS FET TIMER

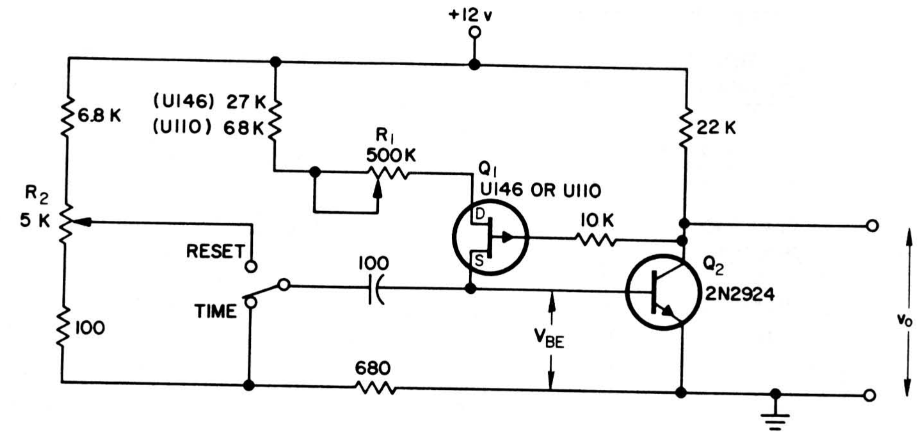


Figure 3

FET TIMER WITH ASSOCIATED SOLID STATE CIRCUITRY FOR MOTOR CONTROL

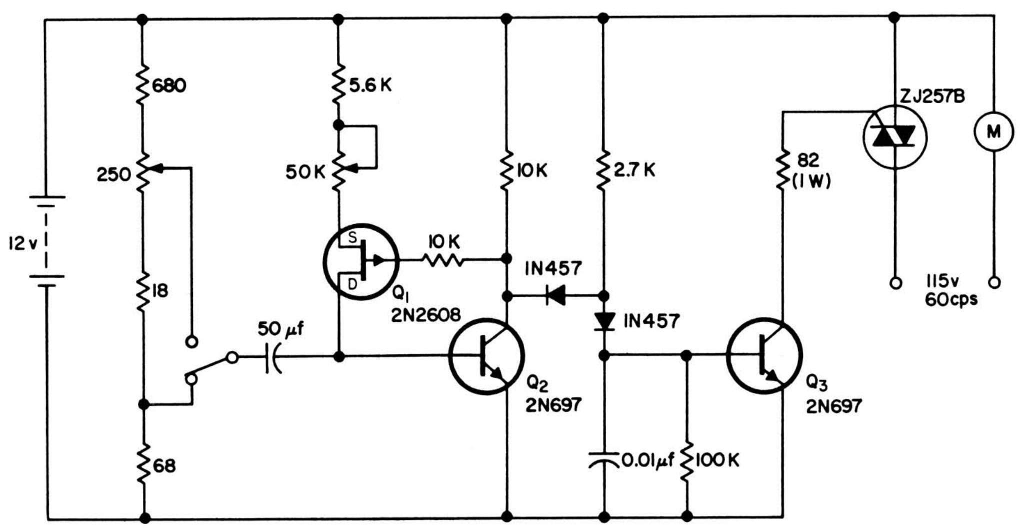
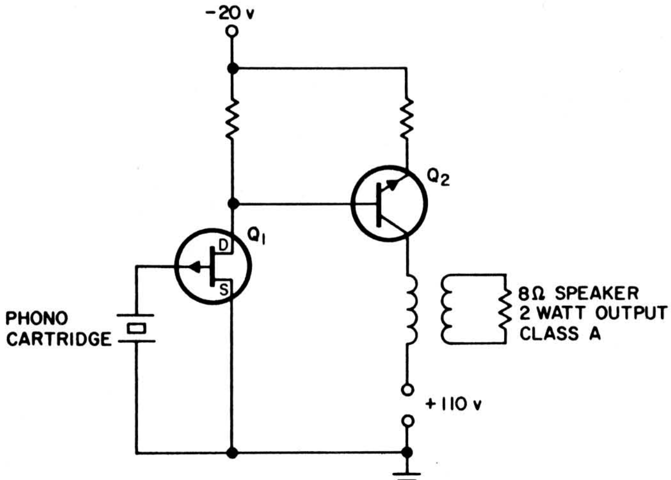


Figure 4

SIMPLE PHONO PREAMPLIFIER WITHOUT TONE OR VOLUME CONTROLS
FET REPLACES 2 OR 3 BIPOLAR TRANSISTORS



Q_1 g_{fs} > 1500 μmho, SIMILAR TO U-149
Q_2 BV_{CES} > 200v
h_{fe} > 90
I_C = 45 ma

Figure 5

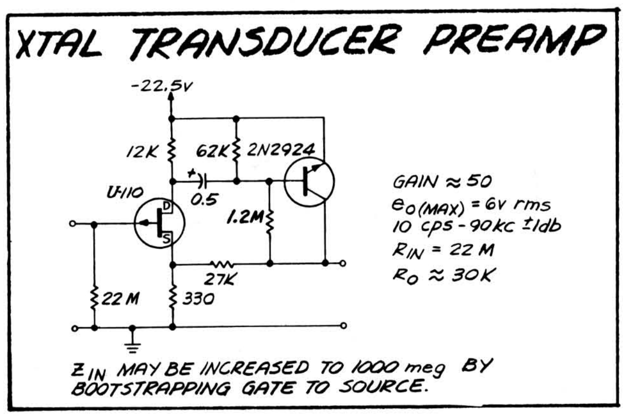


Figure 6

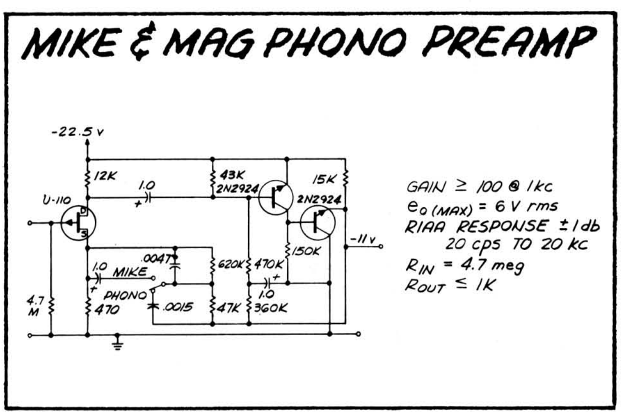


Figure 7

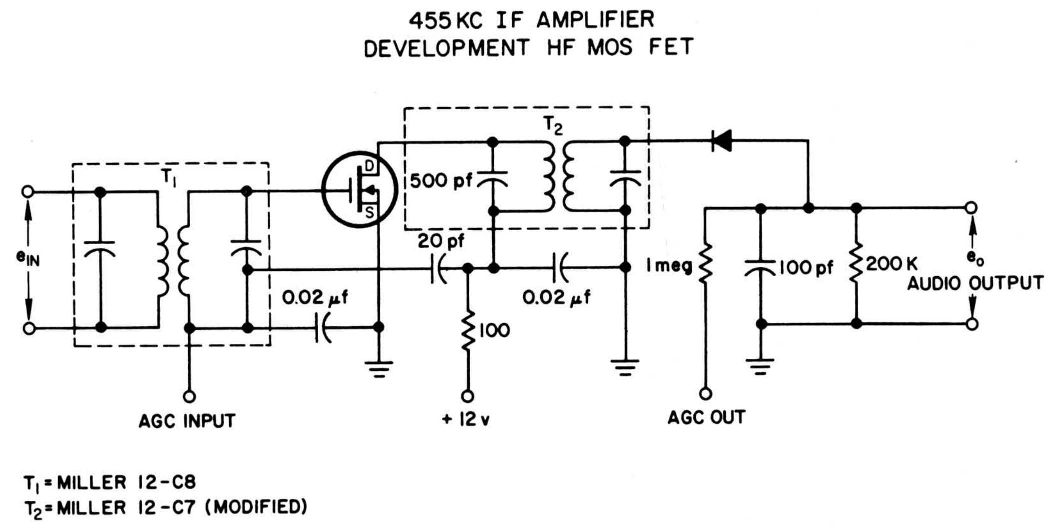


Figure 8

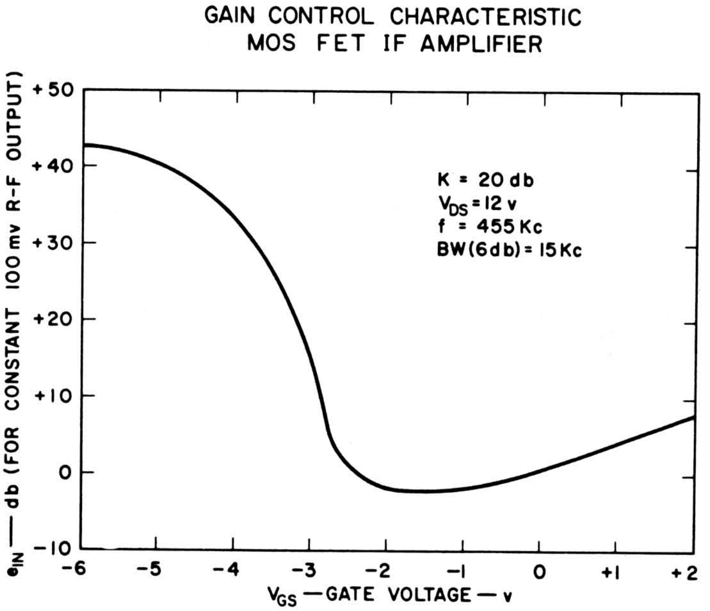
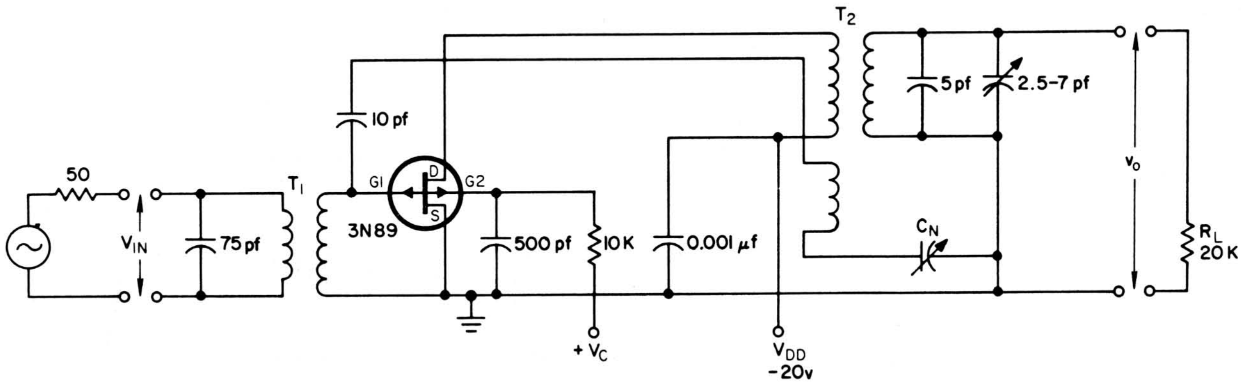


Figure 9



T_1 = J. W. MILLER TYPE 6231

T_2 = J. W. MILLER TYPE 6234
WITH A TWO TURN LINK AT LOW END

C_N = 0.8 TO 13 IN PARALLEL WITH 5 pf FIXED

TYPICAL GAIN +15db FOR V_C=0

TYPICAL AGC RANGE 40db

Figure 10

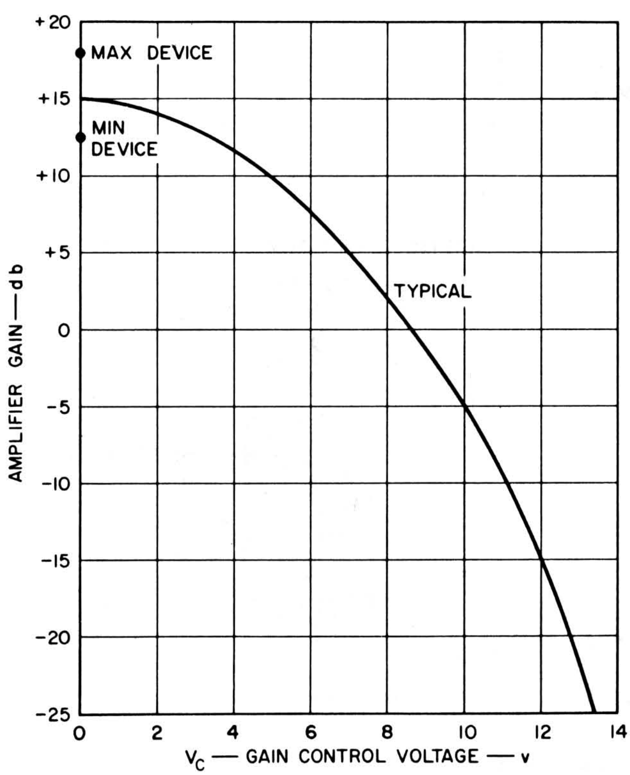


Figure 11

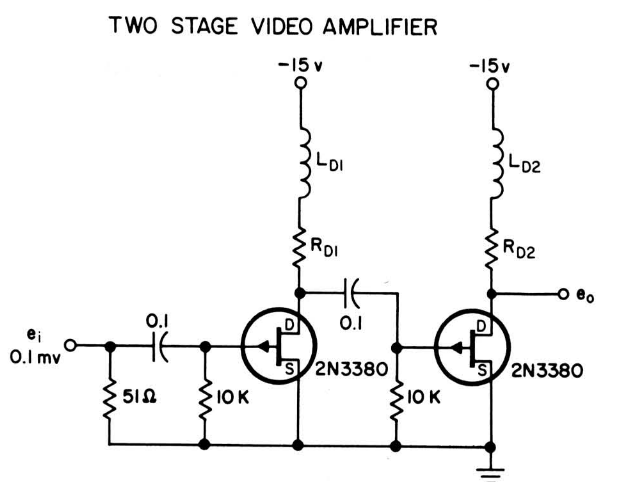


Figure 12

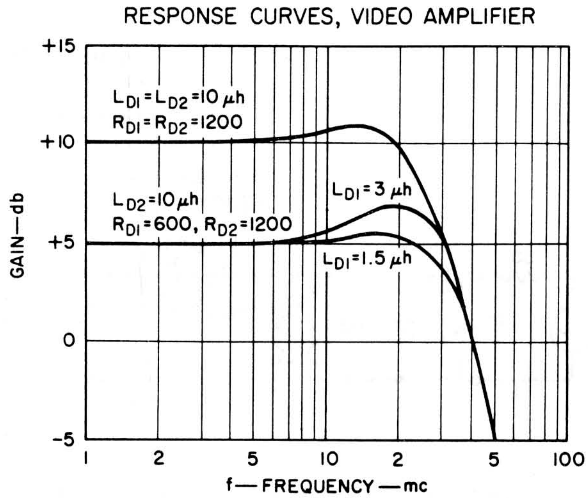


Figure 13

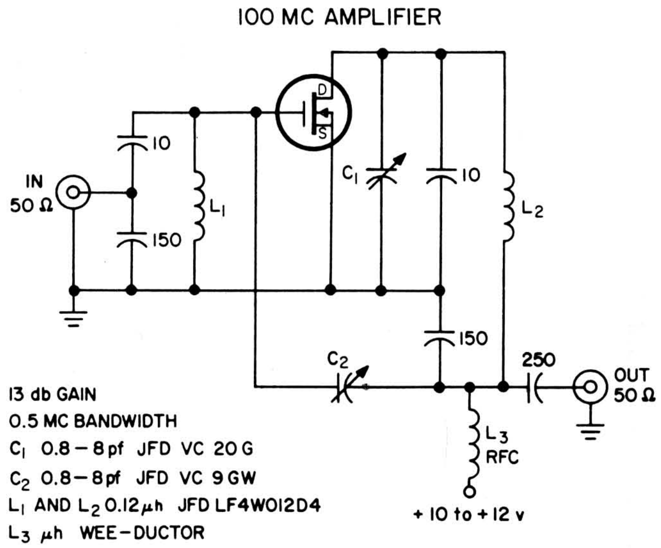


Figure 14

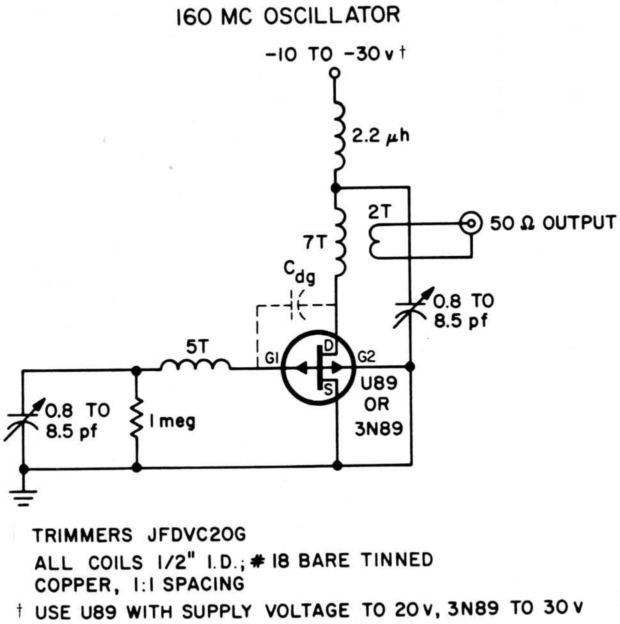


Figure 15

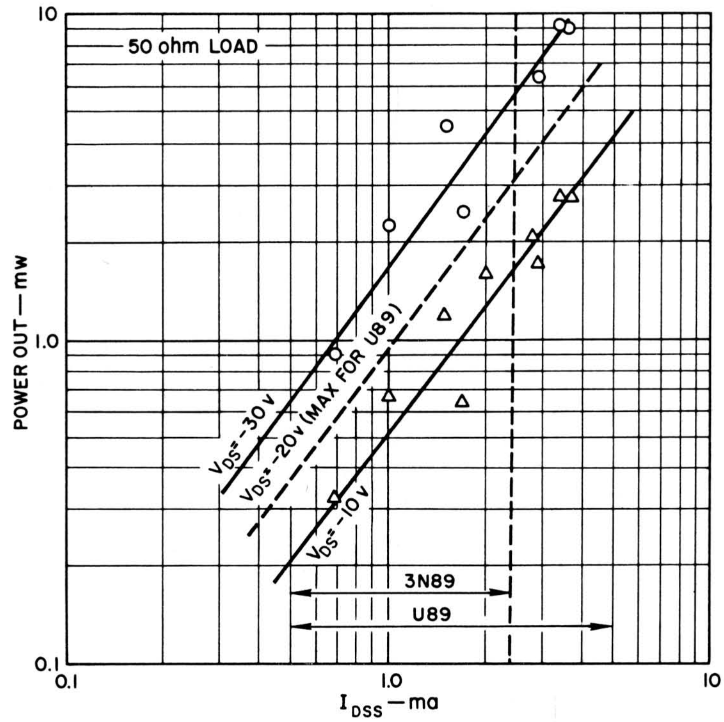


Figure 16

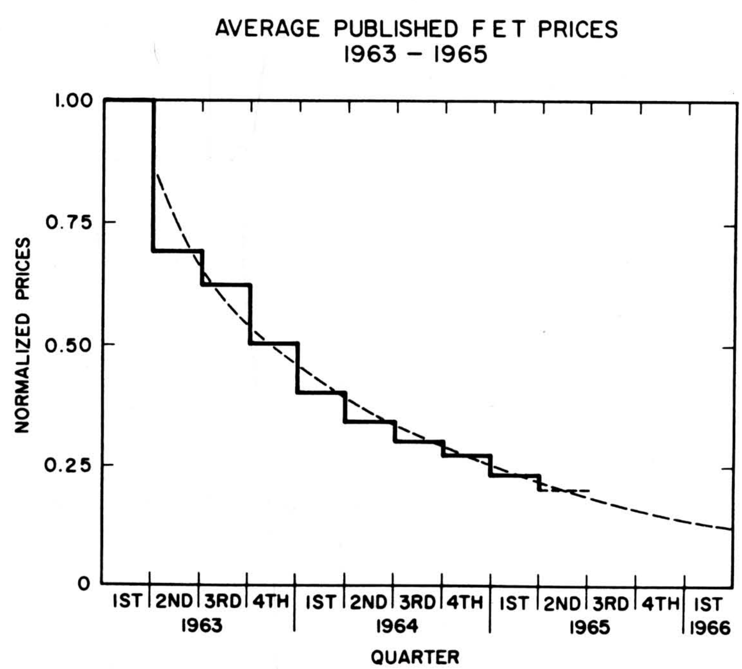


Figure 17