Four Ways to
And Conventional

Field-effect and regular transistc cuit pairs that give very high needed to utilize these gains. Tl basic combinations possible with I effect transistors and regular sili

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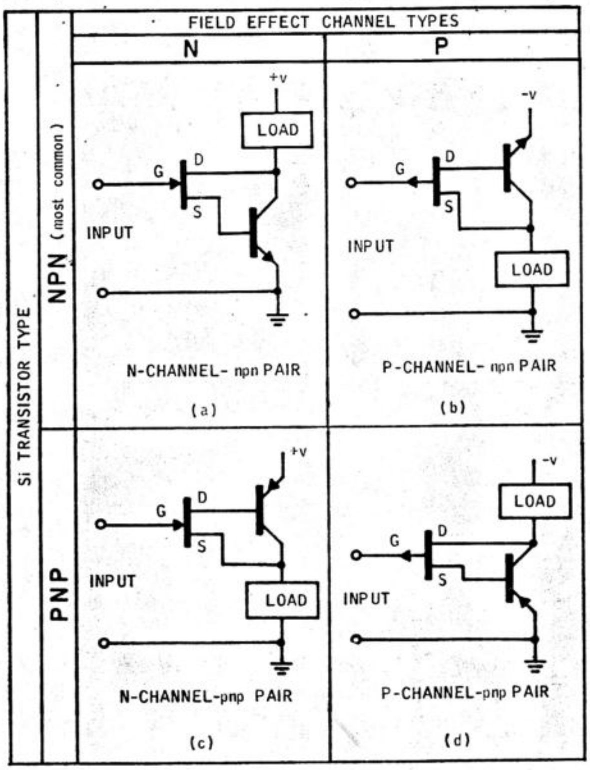
Table 1. Matrix of Possible Combinations



A COMBINATION of the new field-effect transistor and a conventional bipolar transistor offers the circuit designer extremely high input impedance, low noise and high voltage or power gain. There are several ways of interconnecting these pairs and the circuit designer should know the basic characteristics of each.

The two combinations that first come to mind are an n-channel field-effect device ("pnp") driving an npn transistor, or a p-channel field-effect ("npn") driving a pnp transistor. These are shown as (a) and (d), respectively, in the matrix of possible combinations, Table 1.

The characteristics of this pair are not entirely obvious since the base-emitter diode characteristics of the transistor are reflected

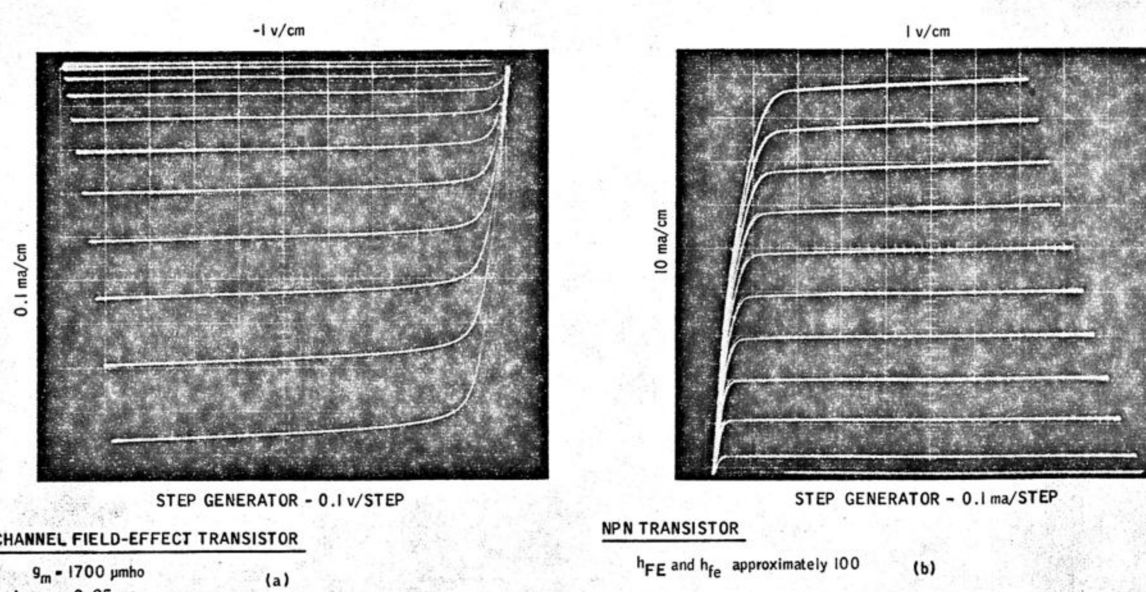


Fig. 1. Individual characteristics of the field-effect devices and transistors that w produce the results of Fig. 3. Note that the characteristics of npn and pnp transis closely matched despite their opposite polarities.

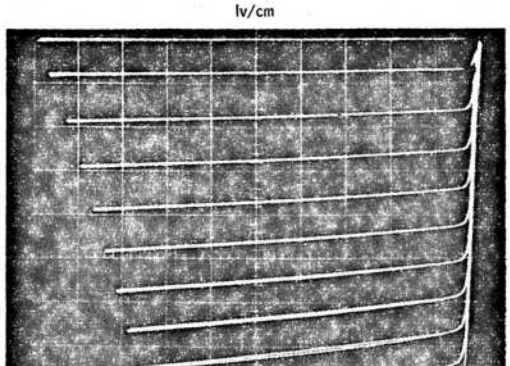
Pair Field-Effect
ıl Transistors

***stors can be combined into cir-
ıh gains along with low noise
The author describes the four
h N-channel and P-channel field-
silicon transistors.***

back to change the characteristics of the field-effect device. In other words, some source degeneraton is present. Since the field-effect device is quite similar to a vacuum-tube pentode, this phenomenon can be compared to cathode degeneration in a pentode. The degenerative effect of this diode is twofold:

- The normal input impedance of the transistor, which varies with base-emitter current, may introduce undesirable non-linearities for large signal swings.
- The forward voltage drop across the base-emitter diode effectively biases the gate-source diode of the field-effect device in such a fashion that transconductance is reduced.

As a matter of fact, if the pinch-off voltage of the field-effect transistor is below 0.60 v, the pair may effectively be shut off until a positive bias is applied to the gate, in the



STEP GENERATOR - 0.1 ma/STEP

PNP TRANSISTOR

h_{FE} and h_{fe} approximately 100

(c)

at will be combined to
ansistors (b) and (c) are

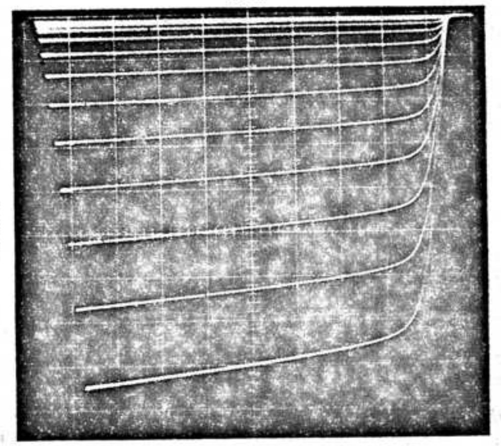
case of the p-channel-pnp pair. (This will be described in conjunction with Fig. 2.)

Types Can Be Mixed By "Flipping" Transistors Connections

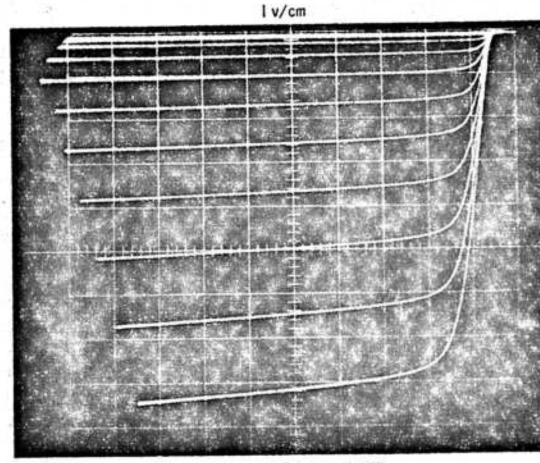
A less obvious combination is the p-channel-npn or n-channel-pnp pair shown in Table 1, b and c. This type of interconnection causes the load to act as the degenerative element in the field-effect source.

Figs. 1 and 2 show typical curve tracer characteristics for individual devices and pairs. Figs. 1a, 1b and 1c show the individual-unit output characteristics of a p-channel field-effect transistor, an npn medium-power transistor and a pnp medium-power transistor. Note that the characteristics of the two conventional transistors, particularly the ac and dc current gains, are quite similar.

Figs. 2a and 2b show the output char-



STEP GENERATOR = 0.1 v/STEP
(a) P-CHANNEL-pnp



STEP GENERATOR = 0.1 v/STEP
(b) P-CHANNEL-npn

Fig. 2. Characteristic curves for field-effect-convention transistor pairs: a) for a P-channel—pnp pair, and for a P-channel—npn pair. The more obvious combin tion for the P-channel field effect—the combination usi the pnp transistor—has the smaller transconductan (34,000 vs 170,000 for the pair using the npn transisto

acteristics of the same units connected as p-channel-pnp and p-channel-npn pairs.

The approximately 0.6-v offset near the origin shows the voltage where the emitter-base diode of the transistor starts conducting in the forward direction. Although the characteristics appear similar, there is a five-fold difference in the output current and transconductance of the two pairs.

This is caused by the biasing effect of the emitter-base diode of the pnp transistor in the source of the field-effect device. The characteristics of each combination may or may not be desirable, depending on the particular design requirement.

Four-Terminal Approach Makes Pair More Flexible

More flexible circuit design is possible if the pairs are used as four-terminal devices with the source or drain brought out separately. The appropriate element then can be connected directly to the power supply. In the case of the p-channel-npn pair this minimizes the degenerative effect of the load in the source and the normal characteristics of the field-effect device are maintained.

In the case of the p-channel-pnp pair the effect of separately biasing the drain is less apparent, but some improvement can be noted. Typical output characteristics for the latter pair are shown in Fig. 3.

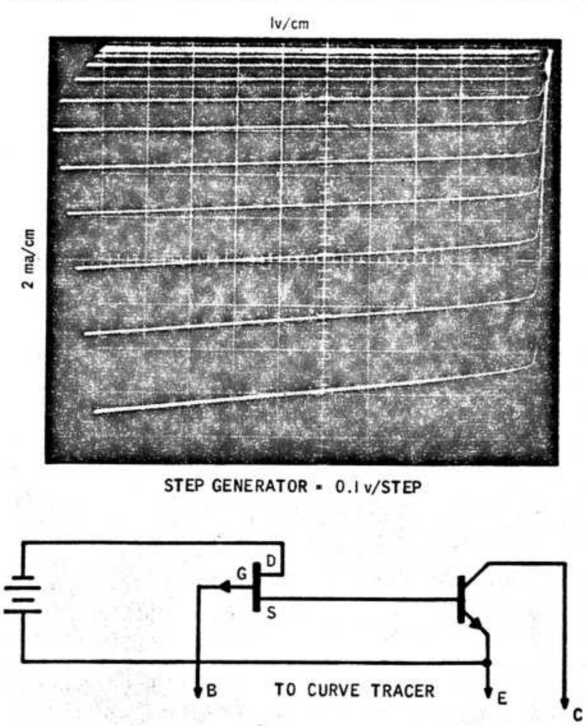


Fig. 3. Another possibility with these pairs is using separate biasing for the two active units. Note the slight alteration of the curves, as compared with Fig. 2a.

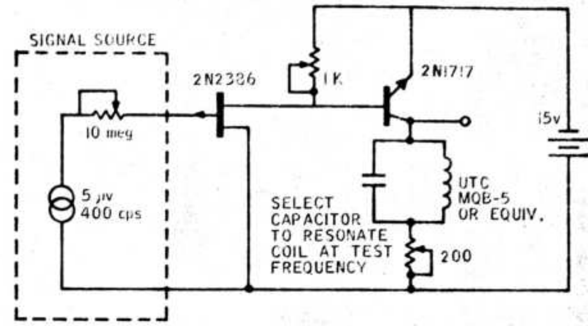


Fig. 4. Simple laboratory-type circuit using field-effect-conventional transistor pair: In more sophisticated circuits, conventional biasing and feedback techniques could be used, with some of the gain sacrificed for stability vs time and temperature.

In some cases the output current of the field-effect device may be too large to feed directly into the base of the transistor. When this happens, the field-effect device can be biased so that less current flows, or a resistor may be used to shunt the base-emitter diode of the transistor. The relative desirability of the two methods will depend on the devices used and the circuit requirements.

Very High Voltage Gains Possible With Hybrid Pairs

When field-effect devices and transistors are paired as described, very high voltage and power gains can be achieved. For example, the pair shown in Fig. 2b has a combined small signal transconductance of approximately 170,000 micro-mhos. If a 6-K load impedance can be realized, the voltage gain will be greater than one million.

The inherent low noise and high input impedance of the field-effect device are such that gains of this magnitude can be achieved and utilized. This type of circuitry is particularly handy when the signal source is a high-impedance transducer with an output of only a few microvolts (such as an infra-red cell).

In addition to the high-gain, low-noise characteristics of the pair, some degree of temperature compensation is achieved since the gain of the field-effect device decreases with temperature, while the gain of the transistor increases with temperature.

A simple laboratory-type circuit that shows the capability of unipolar-bipolar transistor pairs is shown in Fig. 4.

In more sophisticated circuits, conventional biasing and feedback techniques can be used, and some of the available gain traded off for better stability versus time and temperature. ■ ■