USING THE NEW CONSTANT-CURRENT DIODES

By DONALD E. LANCASTER

These semiconductors maintain a constant current over a wide range of terminal voltage and appear as very high circuit impedances. Uses include over-current protection, transistor biasing, linear ramp generators, and linear ohmmeters.

A NEW type of diode is now available which works exactly the opposite of a zener diode. It is called a *constant-current diode* or *field-effect current-regulator diode*. Unlike a zener, such a diode presents a constant *current* regardless of the terminal voltage over a wide operating range and appears as a very *high* circuit impedance. These new devices are quite useful for a number of electronic applications, including overcurrent protection, transistor biasing, linear ramp and stairstep generators, differential amplifiers, precision reference voltage sources, and linear-scale ohmmeters, to name a few.

Operating Principles

The constant-current diode is basically a field-effect transistor that has its gate and source electrodes shorted together. As Fig. 1 shows, an FET connected this way generates a nearly constant current over a wide voltage range.

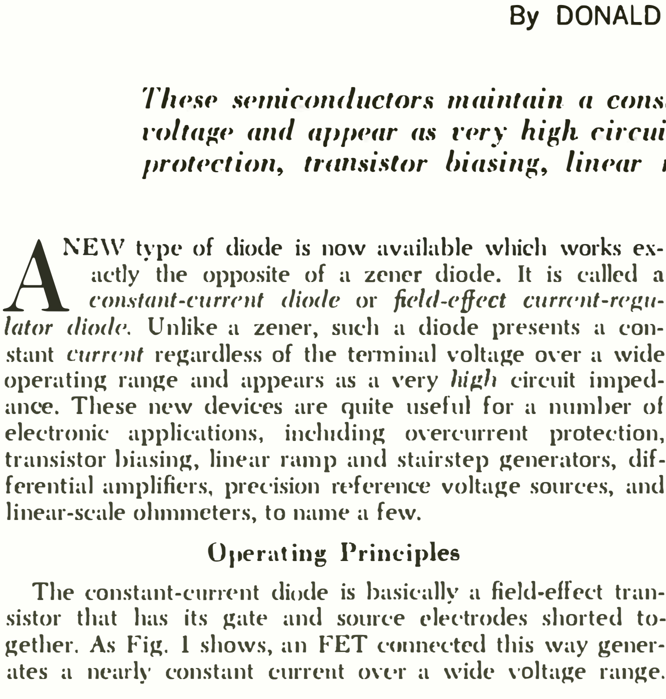
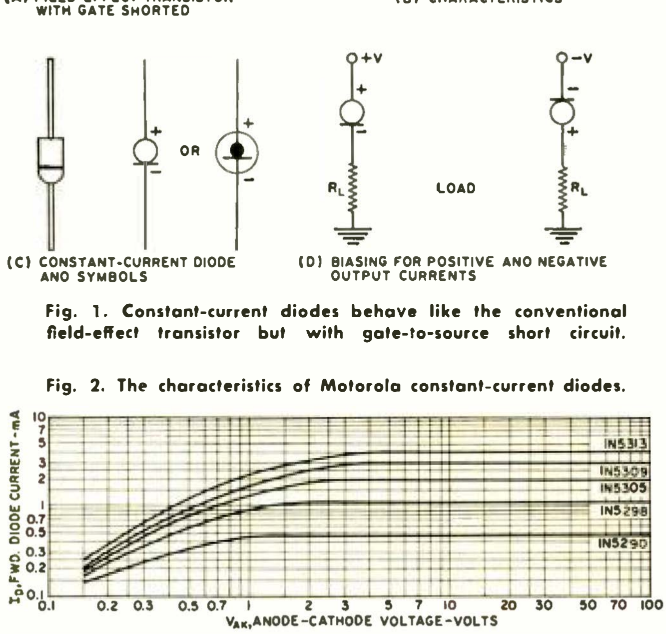


Fig. 1. Constant-current diodes behave like the conventional field-effect transistor but with gate-to-source short circuit.

Fig. 2. The characteristics of Motorola constant-current diodes.



This constant-current region extends from the pinch-off voltage to the forward break-over (breakdown) voltage. In this region, the supply or circuit voltage can vary widely with little or no change in the current the FET allows to pass. Thus, to use a field-effect transistor as a constant-current source, we bias it in the *forward* direction between the pinch-off voltage (usually 1 to 8 volts) and the forward breakdown voltage (25 to 100 volts). Any circuit voltage in this range will result in a constant drain current.

The constant-current diodes are simply field-effect transistors which have been optimized for constant-current service by making the pinch-off voltage very low, the breakdown voltage very high, and the dynamic impedance between these limits as high as possible.

The symbol and polarity of a constant-current diode are shown in Fig. 1C, while Fig. 1D shows the normal biasing and polarity for both positive and negative power supplies. Note that we use the diode in the *forward* direction, unlike a zener diode, which is normally reverse-biased. The diode will provide a constant current *only* when it is properly biased in the forward direction between the pinch-off and breakdown voltages. The constant-current diode should not be connected or biased in the reverse direction.

Available Types & Applications

The 1N5283 through 1N5314 diodes are a family of constant-current field-effect diodes that cover a 220-microampere to 4.70-milliampere range in 32 different currents. Performance of several selected diodes is shown in Fig. 2. These 10% tolerance units operate over a —55 to +200° C range and have a moderate temperature coefficient that must be taken into account in precision circuitry which must operate over a wide temperature range. Maximum diode dissipation is a healthy 600 milliwatts. The pinch-off voltage ranges from 1 to 3 volts, while the forward breakdown is specified at 100 volts, giving a 97- to 99-volt range of constant-current operation.

Being fairly new, these devices are still expensive (about $9 each in single quantities), but since an experimenter can come up with a workable substitute by shorting the gate-to-source leads of a far cheaper FET, it is almost certain that these devices will soon be priced in the $1 to $2 range, comparable to ordinary zener diodes.

One source of the 1N5283 series is *Motorola Semiconductor*, Box 955, Phoenix, Arizona 85001. Data sheets and distributor lists are available. Another source for diodes of this particular type is *Siliconix Inc.* located at 1140 West Evelyn Ave., Sunnyvale, California 94086.

A transistor tester which uses a constant-current diode to establish a constant, known base current independent of supply voltage variations and transistor voltage drops is shown in Fig 3A. The milliammeter then measures the collector current, directly indicating the d.c. current gain of the transistor. For *p-n-p* operation, the supply, the meter, and the constant-current diode must be reversed in polarity. A switch readily accomplishes this in a practical circuit.

Extension of this simple technique allows the current-limiting diode to be used for constant-current biasing of conventional transistor and FET amplifiers. Fig. 3B shows how a constant-current diode saves parts while biasing a transistor differential amplifier. A single diode replaces the transistor, zener, and two resistors normally used to provide a constant total emitter current.

Another important circuit application is as "active loads" for an amplifier where a substantial increase in voltage gain may be obtained. For instance, the gain of an FET amplifier is proportional to the transconductance and the load resistance. Suppose we bias an FET from a 6-V supply with 1-mA current. If we use a resistor, the load impedance will be 6000 ohms or so. If we use a constant-current diode, the load impedance will equal the *dynamic* impedance of the diode (the *slope* of the constant-current portion of the curve), or around 800,000 ohms for a 1-mA diode such as the 1N5297. This allows us to achieve 800/6 or 133 times the gain from the same circuit by simply substituting a constant-current diode for a resistor. To reach the maximum benefits of this voltage amplification, the input impedance to the next stage must be very high.

Turning to other circuit applications, the field-effect diode is ideally suited as a limiter or noise eliminator. In the circuit of Fig. 3C, any input signal between 4 and 100 volts, regardless of the noise and complexity of the waveform, will produce a 1-volt output gate for the duration of the external input signal. This is especially useful for input signal conditioning in electronic counter circuitry.

The same diode serves well as a precision millivolt reference source, where it is desirable to generate a stable and accurate voltage reference at a lower voltage than zener diodes offer. The constant-current diode simply drives a known resistor, producing an output reference voltage whose value is determined by Ohm's law (Fig. 3D).

As an example, a 1N5305 diode (2 mA) and a 250-ohm load will produce a 500-millivolt reference for an input supply voltage from 3 to 100 volts. Diodes in the 400-microampere region can be selected with zero temperature drift and are preferred for wide temperature applications.

A linear-scale ohmmeter may be obtained by a similar technique. Here (Fig. 3E) the resistance is an unknown and the output voltage is measured with a high-impedance voltmeter. If a 1-mA diode is used, the output voltage will equal the resistance in thousands of ohms. A 0 to 10,000 ohm range may be obtained with a 0-10 volt meter range. The scale is linear instead of extremely cramped at one end as in an ordinary ohmmeter, allowing much easier selection of matched resistors, and more uniform accuracy of measurement.

A current-limiting diode may be combined with a zener diode to obtain much better voltage and temperature performance than a zener could provide by itself. The circuit connection is shown in Fig. 3F and may be used whenever a precision, temperature-stable reference voltage is required.

Capacitor Charging and Linear Ramps

The constant-current diode may be combined with a capacitor to produce a highly linear saw-tooth or sweep waveform, according to the formula $C = It/V$, where C is in microfarads, I is in milliamperes, t is in milliseconds, and V is the voltage. For instance, a 1-mA diode will charge a 0.5-microfarad capacitor to 10 volts in 5 milliseconds. The basic charging circuit is shown in Fig. 4A.

In a conventional *RC* charging (*Continued on page* 78)

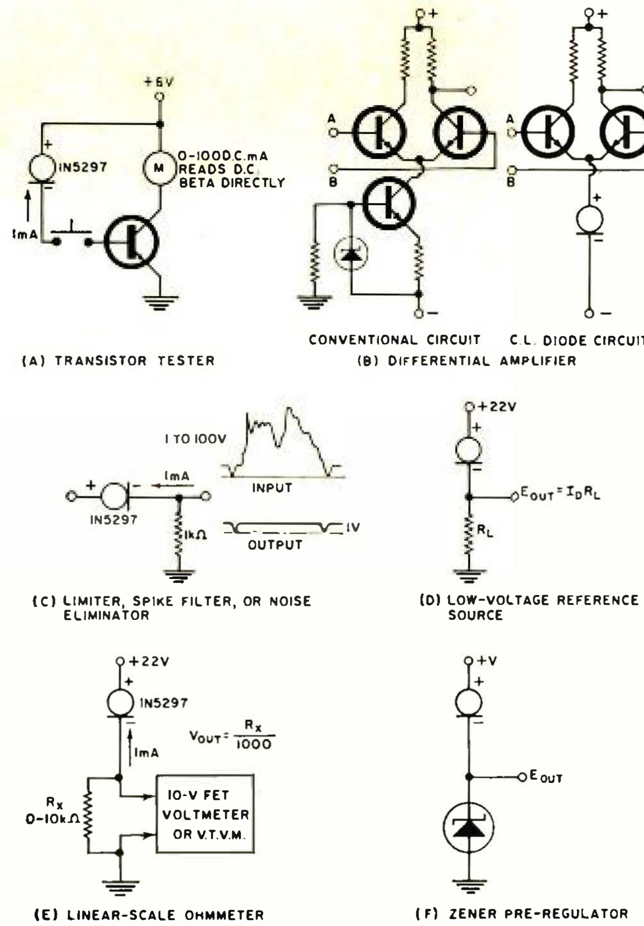
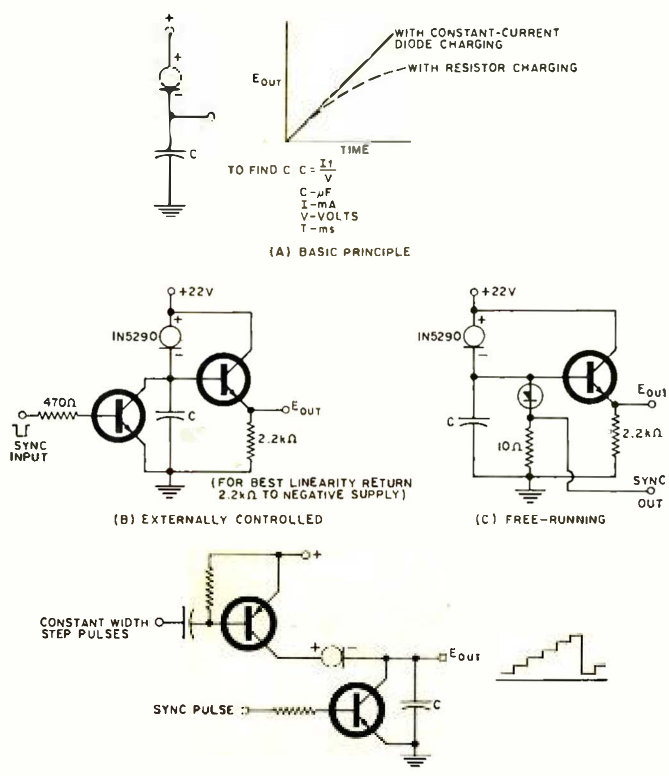


Fig. 3. A number of useful applications for the new diodes including transistor tester; differential amplifier; limiter, spike filter, or noise eliminator; low-voltage reference; linear-scale ohmmeter; or zener pre-regulator. Refer to article.

Fig. 4. Ramps and saw-tooth circuits employing the diodes: (A) The basic operating principle, (B) externally controlled, (C) free-running, and (D) stairstep generator. Operation of each of these circuits is discussed in detail in the text.



Constant-Current Diodes

(*Continued from page 31*)

circuit, the voltage drop across the charging resistor changes the charging current, producing the familiar non-linear exponential waveform. This form of nonlinearity is completely eliminated in a constant-current diode charging circuit, for the charging current remains independent of the voltage across the diode. We must, of course, stop the sweep before the diode goes out of its pinch-off region, or we will obviously lose linearity.

A practical, externally controlled sweep circuit is shown in Fig. 4B. Here we have added an emitter-follower output to keep any load from disturbing the capacitor charge and have added a synchronizing transistor to discharge the ramp upon command from a sync pulse. Normally, the sync transistor is provided base current until a sweep is desired. The sync transistor is then turned off and a linear ramp is produced which is terminated either by limiting on the supply voltage or by once again providing base current to the sync transistor. The beginning of the sweep will be non-linear due to the emitter-follower not being forward-biased. This effect may be overcome by routing the 2200-ohm emitter resistor to a negative voltage.

A free-running sweep is shown in Fig. 4C. Here, the capacitor charges up to the breakdown voltage of the four-layer diode which snaps "on" and discharges the capacitor. The four-layer diode then turns "off", and a new sweep begins. There are two outputs. The emitter-follower output provides a linear, free-running saw-tooth, while the 10-ohm output provides a sharp 10-volt synchronizing spike at the end of each ramp. A constant-current diode used in this circuit must provide less current than the holding current of the four-layer diode. Otherwise, the circuit will latch "on" after one cycle. About 0.5 mA or lower current sources are recommended for operating most of these four-layer diodes.

If we turn the constant-current source "on" and "off", we can produce a stair-step generator with a controllable number of equal-height steps, as in Fig. 4D. Since charge equals current multiplied by time, the longer we leave the diode "on", the higher each step will be, with the dwell time on the steps being determined by the "off" time between charging times. Such a circuit is most useful in transistor and tube type curve tracers and particularly in gray-scale generators in dot and bar service-type generators. Obviously more elegant forms of the same circuit can be used to produce accurate voltage-to-frequency converters. ▲