Op-amp circuit measures diode-junction capacitance

by D. Monticelli and T. Frederiksen
National Semiconductor Corp., Santa Clara, Calif.

For measuring the small-signal junction capacitance of a semiconductor diode, this simple circuit has two advantages over conventional capacitance bridges or meters. The ac test voltage is low enough to avoid excessive modulation of the diode's depletion layer. (Many conventional capacitance meters use such high ac voltages that their readings do not accurately represent the small-signal characteristics of the diode.) And a variable dc bias voltage can be applied to the diode, making the circuit more flexible.

As shown in Fig. 1, the diode is connected to the inverting input terminal of an LM324 operational amplifier, and ac and dc voltages are applied to the noninverting input terminal. The values of the input and output voltages, v_i and v_o, are read on high-impedance voltmeters. The diode junction capacitance, C_J, is then

$$C_J = C_F\,(v_o - v_i)/v_i$$

where C_F is the known value of the capacitance in the op-amp feedback loop. In the circuit shown here C_F and v_i have been made numerically equal (10 picofarads and 10 millivolts, respectively), so

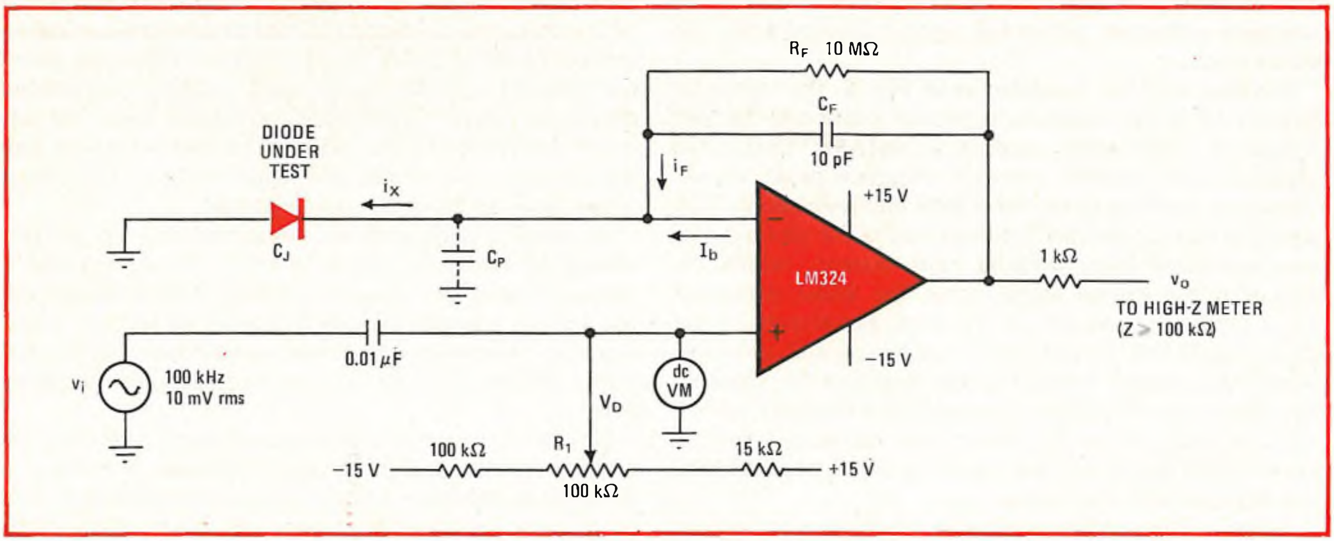
$$C_J = (v_o - v_i)\,pF/mV$$

The dc voltage, V_D, that is applied to the noninverting terminal can be varied through the range from 13 volts to −1 V by means of potentiometer R_1. As a result of the feedback, this voltage appears at the inverting input and is impressed across the diode to provide any value of reverse bias from −13 V to the verge of conduction. The ac input voltage, v_i, is made small to avoid excessive modulation of the junction's depletion layer; 10 millivolts rms is a good value. Voltage v_i is also impressed across the diode through the action of the op amp. C_F and C_J then make up a simple ac voltage divider so that $C_J = C_F\,(v_o - v_i)/v_i$.

Feedback resistor R_F provides a path for the input-bias current of the LM324 (typically 45 nanoamperes), which allows the amplifier to impress V_D across the diode. In doing so, it offsets the dc-output voltage slightly, but does not affect operation. The actual dc-output voltage is given by $V_O = V_D - I_b R_F$. R_F must be chosen carefully; too large a value offsets V_O excessively, and too small a value (relative to the reactance of C_F at the operating frequency) introduces phase shift.

When i_F is out of phase with i_X, the simple capacitive divider relation does not hold, and phasor relationships must be considered. A value of 10 megohms for R_F is practical if the frequency is about 100 kilohertz because the reactance of even a 10-picofarad C_F is only 160 kilohms and gives a phase error of only 1°. Furthermore, the real part of the 324's input impedance shunts C_J slightly and phase-shifts the diode current i_X in the direction of i_F, thereby minimizing the phase difference between the two currents.

To achieve good results in measuring small values of capacitance, the parasitic capacitance C_P that shunts C_J must be accurately known. The parasitic capacitance consists of stray capacitance C_{STRAY} and the input capacitance of the LM324 op amp C_{IN}. The C_{STRAY}, lead and socket capacitance, is independent of V_D. The input



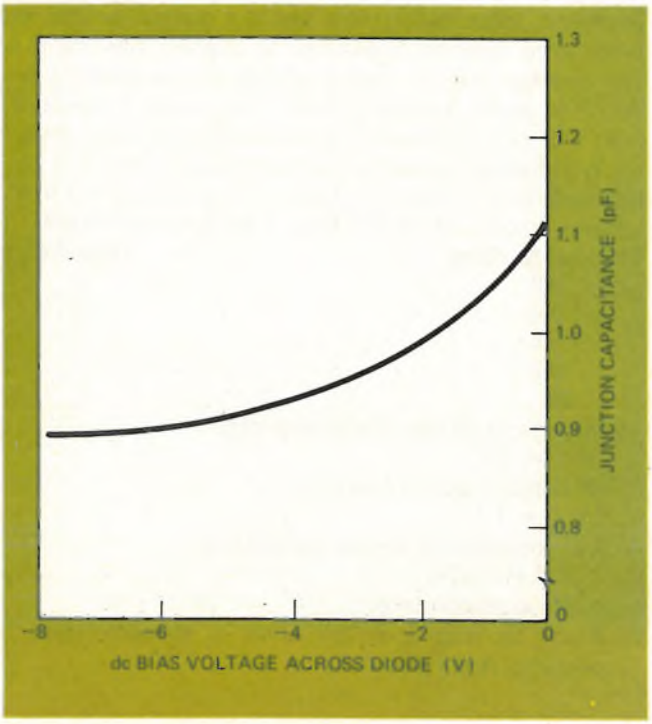
1. Measuring capacitance. Junction capacitance of a semiconductor diode is measured as a function of dc-bias voltage in this circuit. Diode is connected to inverting input terminal of LM324 operational amplifier, and dc-bias and ac-test voltages are applied to noninverting input terminal. Low ac test voltage avoids excessive modulation of depletion layer, for accurate measure of small-signal junction capacitance.

capacitance of the 324 is dependent on V_D (C_{IN} typically is 0.85 to 0.75 pF for common-mode voltages of 5 to 20 V). Fortunately C_{STRAY} usually dominates. Operating the 324 with positive and negative supplies while simultaneously restricting the input voltage to –1 V on the low end of the V_D range reduces the voltage dependence of C_{IN}. In the authors' circuit, C_P measured 3.55 pF with V_D = –1 V and 3.45 pF with V_D = 13 V. A differential measuring technique, first measuring C_P with the diode out of the circuit and then measuring (C_P + C_J) with the diode in, gives the best results. C_F should be a low-tolerance capacitor (a good silver-mica was used by the authors). The pin-to-pin parasitic capacitance of the LM324 that shunts CF is negligible if the board layout minimizes adjacent lead length between the inverting and output pins.

Figure 2 shows a plot of junction capacitance in relation to reverse bias for a 1N914 diode as measured by the circuit in Fig. 1.

Those who want a self-contained unit can use the remaining three op amps in the quad LM324 package plus two additional amps from the dual LM358; both will operate from +9-V and -9-V batteries because of their small current drain. One amplifier can be wired as a Wien-bridge oscillator to supply v_i, while two others can peak-detect voltages v_i and v_o. These peak-detected voltages can then be differenced by a fourth amplifier, and a fifth amplifier can be used to drive a 1-mA meter for a direct reading of capacitance in picofarads. A pot in the noninverting leg of the difference amplifier can be used to offset-null the C_{STRAY} of the circuit. □

2. Result. Junction capacitance of 1N914 diode as a function of reverse bias is measured with circuit shown in Fig. 1. Data sheets do not provide all the information on C_J that is sometimes needed. Conventional capacitance meters use ac voltages that are too high for small-signal measurements and do not provide adjustable dc bias.



Fast method converts numbers from base 10 to any other

by Hans Treichel

Siemens Corp., Cherry Hill, N.J.

Engineers, programers, and others who have undergone the drudgery of converting numbers from the decimal system to systems with other bases will welcome this quick and simple conversion method. If a pocket calculator is available, no manual calculation or recording is needed other than jotting down the answer.

A chart is provided as reference for conversion to hexadecimal, octal, and binary numbering systems. The first column provides equal fractional parts of the numbering system to be used; e.g., hexadecimal notation the column is divided into 16 fractional parts 0/16, 1/16, 2/16, 3/16, . . . 15/16. In the other columns, each fractional part is assigned a digit; the digits are assigned consecutively, starting with the smallest fractional part of the numbering system.

The first step in conversion is to divide the decimal number by the base of the numbering system to which you are converting. If the number following the decimal point is greater than or equal to a fractional number in the chart, record the equivalent number as the least significant digit (LSD) in the new numbering system. Next divide the base number into the result of the first step. Look at the chart again and record the equivalent number as the second LSD. Repeat this process until the division produces a number smaller than 1.

As an example, let's convert the decimal number 321 to its hexadecimal equivalent:

1. Divide 321_{10} by 16 to get 20.0625.
2. From the chart, 0.0625 corresponds to 1, so record 1 as LSD.
3. Divide 20.0625 by 16, getting 1.2539.
4. From the chart, 0.2539 is greater than 0.25 but less than 0.3125, so record 4 as the second LSD.
5. Divide 1.2539 by 16, getting 0.0784.
6. From the chart, 0.0784 is greater than 0.0625 but less than 0.125, so jot down 1 as third LSD.
7. Since the result in step 5 is less than 1, conversion is complete. Answer is 141_{16}.

As you can see, the answer 141_{16} was reached in only seven steps, and nothing had to be written down except the answer itself.

As another example, using the larger digits in hexadecimal notation, convert 687_{10} to base 16:

1. 687/16 = 42.9375.
2. From chart, 0.9375 corresponds to F as the LSD.
3. 42.9375/16 = 2.6836.
4. From chart, 0.6836 corresponds to A as second LSD.