HEWLETT PACKARD
COMPONENTS

Application Bulletin 6

PIN DIODE RF RESISTANCE MEASUREMENT

INTRODUCTION

The most important feature of the PIN diode is its inherent ability to act as a current controlled resistor at rf frequencies. Most diodes possess this capability to some degree, but the PIN diode is especially optimized in design to achieve a wide resistance range while maintaining good linearity and requiring low bias throughout the entire range. As shown in Fig. 1, when the dc bias current is varied from 1 μA to 100 mA, the resistance of a typical PIN diode will change from almost ten thousand ohms to less than one ohm. In order to correctly determine this resistance characteristic of a PIN diode, several test methods have been suggested and devised by various sources. Many of these methods are inaccurate or time-consuming. This Application Bulletin will describe how the RF resistance of a PIN diode can be measured reliably and efficiently with the use of the HP 4815 Vector Impedance Meter.

THE VECTOR IMPEDANCE METER

Operation of the Vector Impedance Meter is based directly on the fundamental concept of driving-point impedance. Driving-point impedance as defined in a series equivalent circuit is the ratio of the voltage applied to the current entering one port of the circuit. This impedance may be represented vectorially as a point in the complex plane having either Cartesian coordinates $R + jX$ or polar coordinates $|Z|/\theta$, where θ is arctan X/R or the angle formed by the voltage and current vectors. The impedance measured by the Vector Impedance Meter is read out in polar coordinates giving a simultaneous indication of magnitude and phase.

A simplified block diagram of the Vector Impedance Meter is shown in Fig. 2. During operation, a CW signal is applied by an oscillator to an amplifier which produces a leveled output. Current from the amplifier is transmitted, first through the device under test and, then, through an ammeter to ground. A sample of current from the ammeter is used as feedback to generate a leveled output from the amplifier. This results in a constant current through the device under test. Since $Z = V/I$ and I is a constant, the magnitude of the impedance is directly proportional to the voltage across the device under test. With the voltmeter across the device under test, the magnitude meter is calibrated directly in terms of impedance. The phase is the delay between the voltage and current outputs. Thus, samples of AC outputs from the voltmeter and ammeter are passed through a phase detector, and the phase meter is calibrated directly in terms of phase angle.

RF CHARACTERISTICS OF A PIN DIODE

The equivalent circuit of the PIN diode at rf frequencies is illustrated in Fig. 3. In this circuit

C_p = Package Capacitance

L_p = Package Inductance

R_{SS} = Substrate Series Resistance

R_I = Junction (I-layer) Resistance

C_I = Junction (I-layer) Capacitance

There is a frequency, f_o, related to lifetime by the expression,

$$f_o = \frac{10}{2\pi\tau} = \frac{1.59}{\tau}$$

above which there is less and less rectification. Thus, at frequencies well above f_o, R_I represents the effective I-layer resistance, which is linearly variable by the dc control current but independent of RF signal level. This resistive behavior illustrated in Fig. 1 is characterized by the equation

$$R_s = KI^x,$$

where

- K = diode resistance at 1 mA (Ω)
- I = the DC control current (mA)
- X = the resistance vs. bias slope
- $R_s = R_{ss} + R_I$ = total diode resistance (Ω)

Since R_{ss} is typically less than 0.1 ohm, it is a negligible contribution to the total diode resistance except at very low resistance levels.

RF RESISTANCE MEASUREMENT

The resistance measurement method to be described utilizes a tunable fixture to tune out the reactive part of the impedance, leaving the real part to be measured by the Vector Impedance Meter. A block diagram of the test equipment is shown in Fig. 4. The diode under test (D.U.T.) in the test fixture receives the proper bias from the current source. The fixture is tuned for a zero phase indication on the Vector Impedance Meter. The resistance is then read on the Vector Impedance Meter or (for better resolution at low resistance levels) on a Digital Voltmeter which is connected to the recorder output of the Vector Impedance Meter. Use of the Precision Power Source to provide a stable low voltage for offsetting the short circuit resistance is described in the Appendix of this Application Bulletin.

With some diodes a single tunable test fixture will tune out the diode reactance for all forward currents. For other diodes more than one test fixture may be necessary.

With the reactive part of the impedance tuned out, the Vector Impedance Meter will essentially see the measured resistance, R_m, as the series combination of the diode resistance, R_s, and the short circuit resistance, R_{sc}, in parallel with the open circuit resistance, R_{oc} as illustrated in Fig. 5. In other words, the measured resistance,

$$R_m = \frac{R_{oc}\left(R_s + R_{sc}\right)}{R_{oc} + R_s + R_{sc}} \qquad (1)$$

The diode resistance is then

$$R_s = \frac{R_m\left(R_{oc} + R_{sc}\right) - R_{oc}\,R_{sc}}{R_{oc}\quad R_m} \qquad (2)$$

or since $R_{sc} << R_{oc}$

$$R_s = \frac{R_{oc}\left(R_m - R_{sc}\right)}{R_{oc} - R_m} \qquad (3)$$

If the measured resistance is low $\left(R_m << R_{oc}\right)$, then the idode resistance

$$R_s = R_m - R_{sc} \qquad (4)$$

For high resistance $\left(R_m >> R_{sc}\right)$

$$R_s = \frac{R_{oc}\,R_m}{R_{oc} - R_m} \qquad (5)$$

The resistance vs. bias slope on a log-log plot is

$$X = \frac{\log R_{s_2} - \log R_{s_1}}{\log I_2 - \log I_1} \qquad (6)$$

where I_1 and I_2 are respectively specified low and high current levels, and R_{s_1} and R_{s_2}, the diode resistances corresponding to those bias levels.

The slope of the HP 5082-3003 and 5082-3004 PIN diodes is specified between 10 µA and 1 mA. In this case equation (6) reduces to

$$X = -\frac{1}{2}\log\frac{R_{10\ \mu A}}{R_{1\ mA}} \qquad (7)$$

Details of the test procedure are contained in the Appendix of this Application Bulletin.

TEST FIXTURE

The test fixture contains a circuit (Fig. 6) which tunes out the diode reactance. The essential components are a tunable inductor and tunable capacitor in the tuning section and an RF choke and bypass capacitor in the bias section.

A photograph of the test fixture appears in Fig. 7. Shown on the test fixture is a Daymarc (Part No. 131-30) Diode Recovery Jig for holding a glass packaged diode under test. Holders for other package types can be easily connected to the "Microdot" SOS Jacks on the fixture. Detailed drawings of this test fixture are available upon request.

SUMMARY

The use of the HP 4815 Vector Impedance Meter in conjunction with a tunable test fixture provides an efficient and reliable means for measuring the RF resistance of a PIN diode.

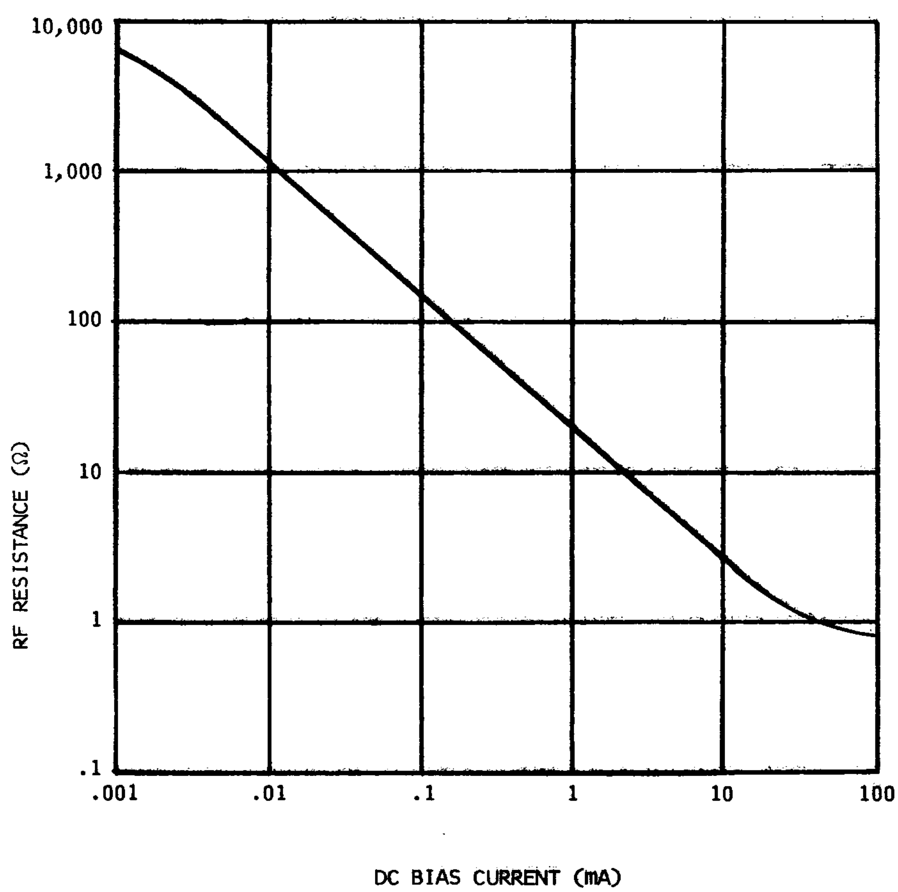


FIGURE 1: THE RF RESISTANCE OF A PIN DIODE WITH VARIATION IN DC BIAS CURRENT.

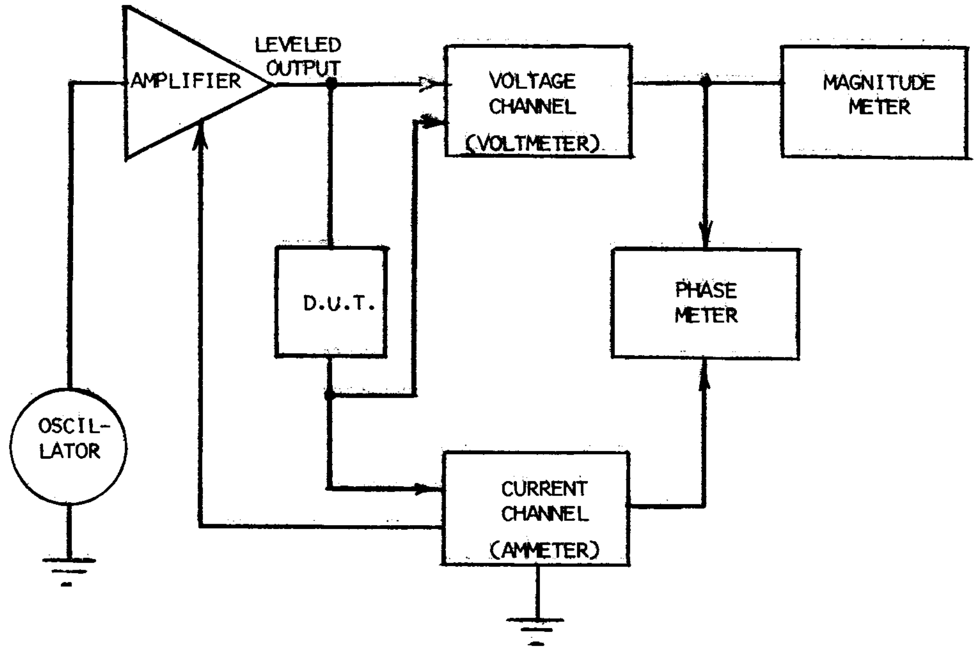


FIGURE 2: SIMPLIFIED BLOCK DIAGRAM OF VECTOR IMPEDANCE METER

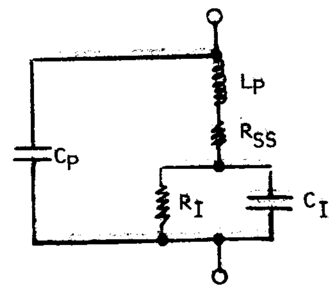


FIGURE 3: EQUIVALENT CIRCUIT OF PIN DIODE AT RF FREQUENCIES

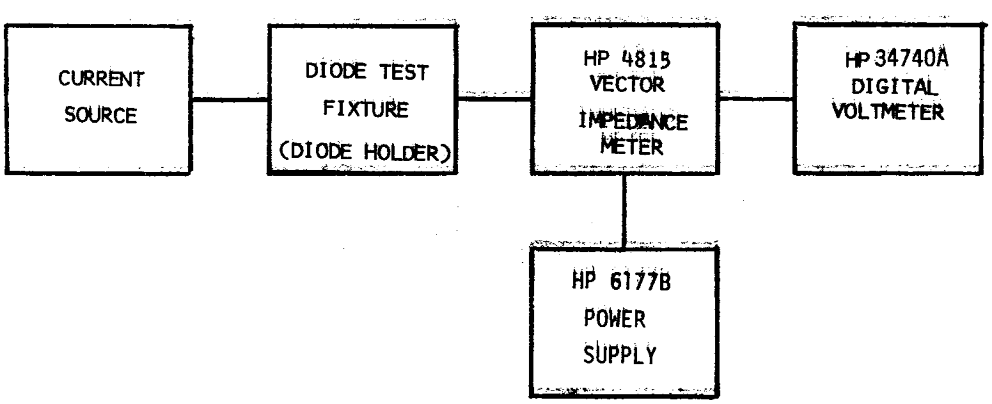


FIGURE 4: BLOCK DIAGRAM OF TEST EQUIPMENT FOR RF RESISTANCE MEASUREMENT OF A PIN DIODE.

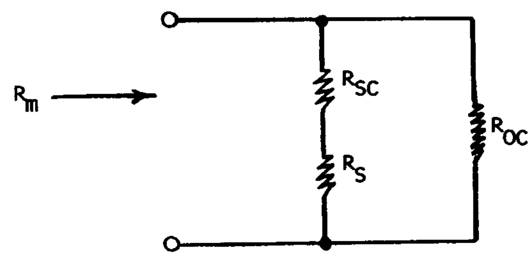
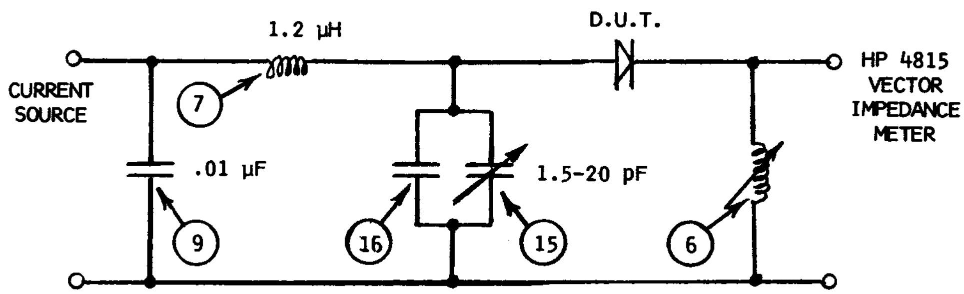


FIGURE 5: THE MEASURED RESISTANCE R_m AS SEEN BY THE VECTOR IMPEDANCE METER WHEN THE REACTIVE PART OF THE DIODE IMPEDANCE IS TUNED OUT.



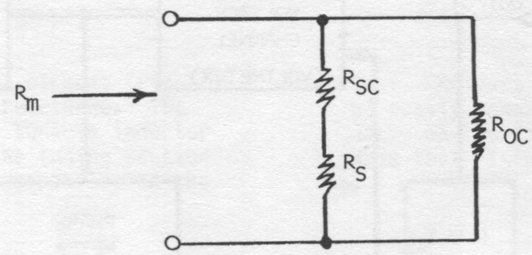
(16) PKG. 15 -30 pF

PKG. 31, 38, 39, 44 -20 pF

(6) SEE DRAWING

FIGURE 6: SCHEMATIC OF TEST CIRCUIT FOR RF RESISTANCE MEASUREMENT OF A PIN DIODE.

FIGURE 7: PHOTOGRAPH OF THE TEST FIXTURE



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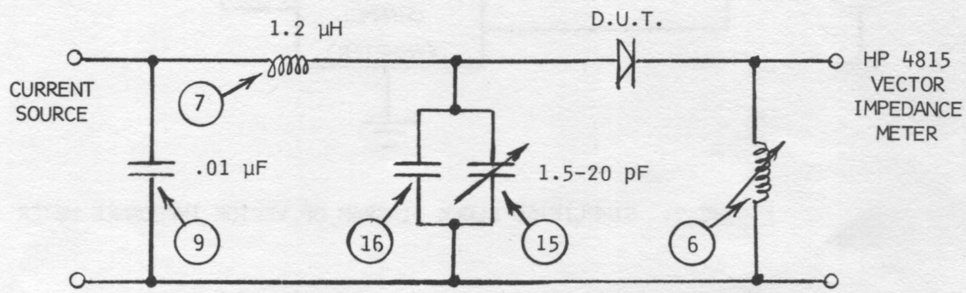

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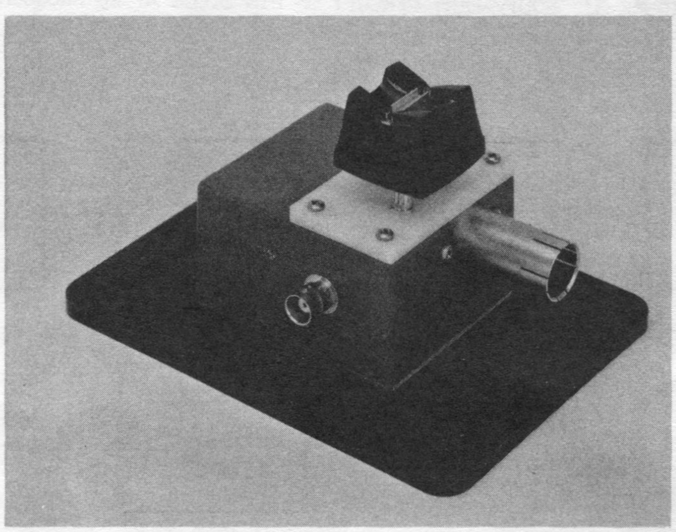

FIGURE 7: PHOTOGRAPH OF THE TEST FIXTURE

I. TEST PROCEDURE

A. LOW RESISTANCE (<40 Ω)

1. With diode under test (D.U.T.) properly biased in the test fixture, the reactive part of the diode impedance is tuned out* in the test fixture (to give zero degree phase as indicated on the Vector Impedance Meter). Resistance, R_m, is read on the Vector Impedance Meter.

2. With a short (which may be a diode lead) across the diode holder, the reactance is tuned out* and the short circuit resistance R_{sc} is read.

3. The diode resistance, R_s, is equal to R_m minus R_{sc} obtained in steps A1 and A2 above.

$$R_s = R_m - R_{sc}$$

For low resistance measurements, better resolution can be achieved with the use of a digital voltmeter connected to the recorder output of the Vector Impedance Meter. If a bucking voltage is connected in series with the recorder output to offset the short circuit resistance, R_{sc}, then the diode resistance, R_s can be read directly on the digital voltmeter.

B. HIGH RESISTANCE (>500 Ω)

1. With nothing in the diode holder, the reactance is tuned out* and the open circuit resistance R_{oc} is read.

2. The diode resistance, R_s, is equal to $\frac{R_{oc} R_m}{R_{oc} - R_m}$ where R_m is obtained as in Step A1 and R_{oc} in Step B1.

$$R_s = \frac{R_{oc} R_m}{R_{oc} - R_m}$$

C. INTERMEDIATE RESISTANCE (40 to 500 Ω)

1. The diode resistance R_s is equal to

$$\frac{R_{oc} R_m - R_{oc} R_{sc}}{R_{oc} - R_m}$$

where R_m, R_{sc}, and R_{oc} are obtained respectively, as in Steps A1, A2, and B1.

$$R_s = \frac{R_{oc} R_m - R_{oc} R_{sc}}{R_{oc} - R_m}$$

II. SLOPE COMPUTATION

The resistance vs. bias slope on a log-log plot is

$$X = \frac{\log R_{s_2} - \log R_{s_1}}{\log I_2 - \log I_1}$$

where I_1 = low bias current
I_2 = high bias current
R_{s_1} = diode resistance at bias I_1
R_{s_2} = diode resistance at bias I_2

for $I_1 = 10\ \mu A$, $I_2 = 1\ mA$

$$X = -\frac{1}{2} \log \frac{R_{10\ \mu A}}{R_{1\ mA}}$$

*Proper tuning is achieved only when the magnitude range on the Vector Impedance Meter is set at the lowest range that gives an on-scale reading. To prevent unnecessary tuning and tampering, a production test fixture is usually made with tuning elements tunable only from the inside of the fixture. For a fixture that is not externally tunable, tuning for zero degree phase is accomplished by adjusting the frequency of the Vector Impedance Meter slightly from 100 MHz.