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Direct Measurement Of Dynamic Capacitance

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edge, the reading is 5% higher than the sheet resistance R_t' in the center. This increase must be attributed to a corresponding reduction of the geometry factor k. Valdes[6] has investigated some special cases of the dependence of k on the proximity of an edge for bulk material.

To determine the contact efficiency η, the sample used for Fig. 2(b) was later provided with electrical connections which allow a measurement of the sheet resistance according to the first conventional method quoted. The result is

$$R_t'/\rho_s = 1.62, \quad (5)$$

which leads, with the use of Eqs. (1), (2) and (4), to a contact efficiency of

$$\eta = 109.5\%.$$

The high value of η may be attributed to both nonspherical shape of the contacts and unwanted elastic deformation of the glass substrate due to insufficient thickness. Notice that k and η compensate each other such that the overall correction is very small.

An attempt was made to determine the limitations of the method. Using a 25×25 mm substrate with a layer of 1 μ Cu, it was found that the sheet resistance determined with k and η was too high by the amount

$$R_p = 0.22\Omega.$$

R_p may be considered the parasitic resistance of the test fixture and represents a lower but not an ultimate limit for the instrument built.

The upper limit was beyond the capability of the test equipment. It is assumed that either insulation problems or electrical breakdown of the test sample will limit the performance of the device.

A method has thus been shown which allows for easy and efficient but somewhat rough testing of the sheet resistance. The only equipment needed apart from a set of contacts is an ohmmeter. The absolute accuracy for a sample of arbitrary shape is of the order of 10%. This figure assumes a minimum distance of $d/2$ of either contact from any edge. It should be noted, however, that for a given set of contacts which is applied to a sample with known k, the relative accuracy is given by $3\sigma \approx 0.6\%$. Apart from a pure resistance measurement, the method has found various other applications, such as measuring the thickness of a thin film with known resistivity, monitoring the composition or obtaining information about the grain structure for a given film thickness.

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Direct Measurement of Dynamic Capacitance

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THE time–domain measurement of dynamic capacitance described is a simple yet sensitive way to obtain capacitance–voltage curves for low-loss devices such as a MOSFET.[1] Deviations of a fraction of a picofarad may be detected using very simple circuits.

Standard methods for measuring dynamic capacitance ($c = dq/dv$, where q is charge and v is voltage) utilize a small ac signal superimposed on the dc bias v to determine driving point impedance. The capacitance is determined from the driving point impedance knowing the frequency. One problem with this method is the low ac signal level required if the capacitance is changing significantly with bias voltage. The time–domain method described in this paper offers a simpler yet more sensitive way to measure dynamic capacitance.

The charging current i for a low-loss device may be used to measure dynamic capacitance if $v(t)$ is known.

$$i = dq/dt$$
$$= (dq/dv)(dv/dt)$$
$$c = dq/dv$$

but

$$i = c\,dv/dt \quad (1)$$

so c is *not* restricted to constant values. A periodic triangular waveform is an excellent selection for $v(t)$, i.e.,

$$v(t) = \begin{cases} (K)\cdot(t - T/4) & \text{for} \quad 0 \le t \le T/4 \\ (K)\cdot(3T/4 - t) & \text{for} \quad T/2 \le t \le T \end{cases}$$

and

$$v(t) = v(t+T) \quad \text{(see Fig. 1).}$$

Then $dv/dt = K$ when the slope of v is positive and $dv/dt = -K$ for negative slope. The capacitor current is then directly proportional to dynamic capacitance at any instant of time, i.e.,

$$i = (\text{SIGN OF THE SLOPE OF } v)\cdot(K)\cdot(c). \quad (2)$$

Several circuits have been used to obtain c–v curves for low-loss devices such as MOSFET's. The simplest is shown in Fig. 2. The series resistor, R, must be small enough so that $v_R \ll v$, therefore $v \doteq v_i$.

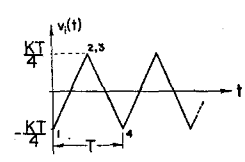

FIG. 1. Triangular waveform.

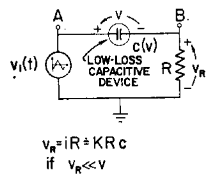

FIG. 2. Circuit to obtain dynamic capacitance vs voltage curves.

A c–v curve will be displayed on an oscilloscope if point A is connected to the vertical amplifier and point B to the horizontal amplifier. Figure 3 shows such a curve for the gate-substrate terminals of a MOSFET with $R=1\ \text{M}\Omega$ (the input resistance of the horizontal amplifier). The vertical calibration depends on the amplitude and frequency of the triangular waveforms. From Eq. (2)

$$c=\frac{(\text{SIGN OF SLOPE OF THE GENERATOR VOLTAGE})\cdot T}{(\text{PEAK-TO-PEAK GENERATOR VOLTAGE})\cdot 2R}\cdot(v_R).$$

That is, $c \propto v_R$.

This circuit may be used for remote observation of c–v curves by using a cathode follower to isolate cable capacitance. The grid resistor is used for R. Stray capacitance, dc bias and common mode noise may be cancelled by building an identical cathode follower on the same chassis and connecting the outputs to a difference amplifier. More sophisticated circuits have been tested using operational amplifiers and feedback principles but they offer little advantage over the simple circuit described which is adequate to measure dynamic capacitances of a few picofarads.

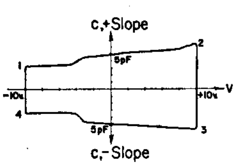

FIG. 3. Gate-to-substrate dynamic capacitance vs voltage curve obtained with the circuit of Fig. 2, using a p-channel, enhancement, MOSFET.

[1] Metal Oxide Semiconductor Field Effect Transistor.

Digital Phase Sensitive Detector*

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THE system described below determines the phase and amplitude of an ac signal buried in noise. It consists of two reversible counters operating as phase sensitive detectors 90° apart. The digital phase sensitive detector has distinct advantages over the corresponding analog circuit. There is no low frequency limit. It will operate at dc as an integrator. The time constant, which is not determined by an RC circuit, can be as long as desired. Since the output is in digital form, it can easily be transferred to a computer for analysis.

A voltage controlled oscillator (Wavetek model 111) functions as an analog-to-digital converter. The input signal modulates the frequency of the oscillator. A reference signal gates the count-up/count-down function of each reversible counter such that one is in phase while the other is 90° out of phase with the reference signal. Thus the oscillator frequency is added for ½ cycle, then subtracted for an equal time. If the average frequency is the same during both half cycles, the counter will read zero at the end of each full cycle. If the frequency is systematically higher during one half and lower during the other half, only then will counts accumulate. The number of counts remaining on each counter after an integral number of cycles will be proportional to the component of the signal in phase with the reference to that counter. Table I shows some examples.

The system is shown in Fig. 1. With no input signal each counter per cycle will drift from zero at the rate of oscillator frequency times fraction asymmetry of reference. To make this drift small compared to signal, a very symmetrical reference was obtained by dividing a 100 kc crystal oscillator. The start/stop circuit allows the counters to run only an integral number of cycles. The timer which activates the stop circuit also determines the time constant (averaging time) of the system.

The digital phase-sensitive detector was designed and built for use in a chemical modulation[1] experiment where the low frequency signal of interest is in the range ¼ to 40 cps. The maximum signal into the voltage controlled

TABLE I. Response of counters to simulated signals.

		First quarter cycle	Second quarter	Third quarter	Fourth quarter	Result
	A.	add	add	subtract	subtract	
	B.	subtract	add	add	subtract	
no signal	A.	+100	+100	−100	−100	0
	B.	−100	+100	+100	−100	0
In-phase signal	A.	+110	+110	−90	−90	+40
	B.	−110	+110	+90	−90	0
90° lag	A.	+90	+110	−110	−90	0
	B.	−90	+110	+110	−90	+40
45° lag	A.	+100	+110	−100	−90	+20
	B.	−100	+110	+100	−90	+20

Signals in other quadrants will have the appropriate signs.
A. counter with in-phase reference.
B. counter with 90° lag reference.