Nearly Direct Measurement of Relative Permittivity

The only quantities measured are two voltages.

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A recently conceived technique for determining the relative permittivity of a material sample at a given frequency is more nearly direct than are prior techniques that involve measurement of such related non-electrical quantities as the size, shape, and/or weight of the specimen. The present technique involves only measurement of two voltages at the frequency in question, followed by calculation of the ratio between the voltages.

The technique requires two circuits — a test circuit and a reference circuit — that are identical except as described below. Each circuit includes a capacitor C_1 connected in series with a much larger capacitor C_2 to form a voltage divider (see figure). C_1 is a parallel-plate capacitor. The top electrode of C_1 is connected to an AC signal source of voltage V_a at the frequency of interest. The top electrode of C_1 is surrounded by a guard electrode that, in turn, is surrounded by a grounded electrode. The bottom electrode of C_1 is connected to the top electrode of C_2. The bottom electrode of C_2 is grounded.

The volume enclosed by the top, bottom, and guard electrodes of C_1 constitutes a sample cell. A material sample, having relative permittivity k at the frequency of interest, is placed in the sample cell. The exact shape and size of the sample volume is not critical and can be chosen to fit the material sample. What is critical is that (a) C_2 in both circuits be identical and (b) the sample cell in the test circuit have the same size and shape as that in the reference circuit, so that the capacitances of the two sample cells are proportional to the permittivities of their contents. Then the capacitances of the two sample cells are given by

$$C_{1\text{test}} = k_{\text{test}} C_0 \text{ and}$$
$$C_{1\text{reference}} = k_{\text{reference}} C_0,$$

where C_0 = the capacitance of either sample cell when it is empty.

For each circuit, the voltage between the (C_1,C_2) junction and ground is given by

$$V_2 = V_a C_1/(C_1+C_2).$$

Inasmuch as $C_2 >> C_1$, this voltage is closely approximated by

$$V_2 \approx V_a C_1/C_2.$$

For the test and reference assemblies, respectively, this relation becomes

$$V_{2\text{test}} \approx V_a C_{1\text{test}}/C_2 = V_a k_{\text{test}} C_0/C_2 \text{ and}$$
$$V_{2\text{reference}} \approx V_a C_{1\text{reference}}/C_2 = V_a k_{\text{reference}} C_0/C_2.$$

Then taking the ratio between the two V_2 measurements, one obtains

$$k_{\text{test}}/k_{\text{reference}} \approx V_{2\text{test}}/V_{2\text{reference}}.$$

The sample can be a liquid, a solid, a granular material, or a mixture of materials: the technique is valid for almost any dielectric material or combination of materials, the only requirement being that the sample fill the sample cell in the test circuit. If the sample cell in the reference circuit is kept empty (in which case $k_{\text{reference}} = 1$), then the relative permittivity of the material sample in the test cell is given simply by

$$k_{\text{test}} \approx V_{2\text{test}}/V_{2\text{reference}}.$$

In the original application for which the technique was developed, the material to be tested was to be a granular one containing an unknown amount of moisture (representing moist soil), while the reference material was to be a dry sample of the same granular material. Assuming that the permittivity varies linearly with the moisture constant, one could estimate the moisture content as being approximately proportional to

$$(k_{\text{test}}/k_{\text{reference}}) - 1 \approx (V_{2\text{test}}/V_{2\text{reference}}) - 1.$$

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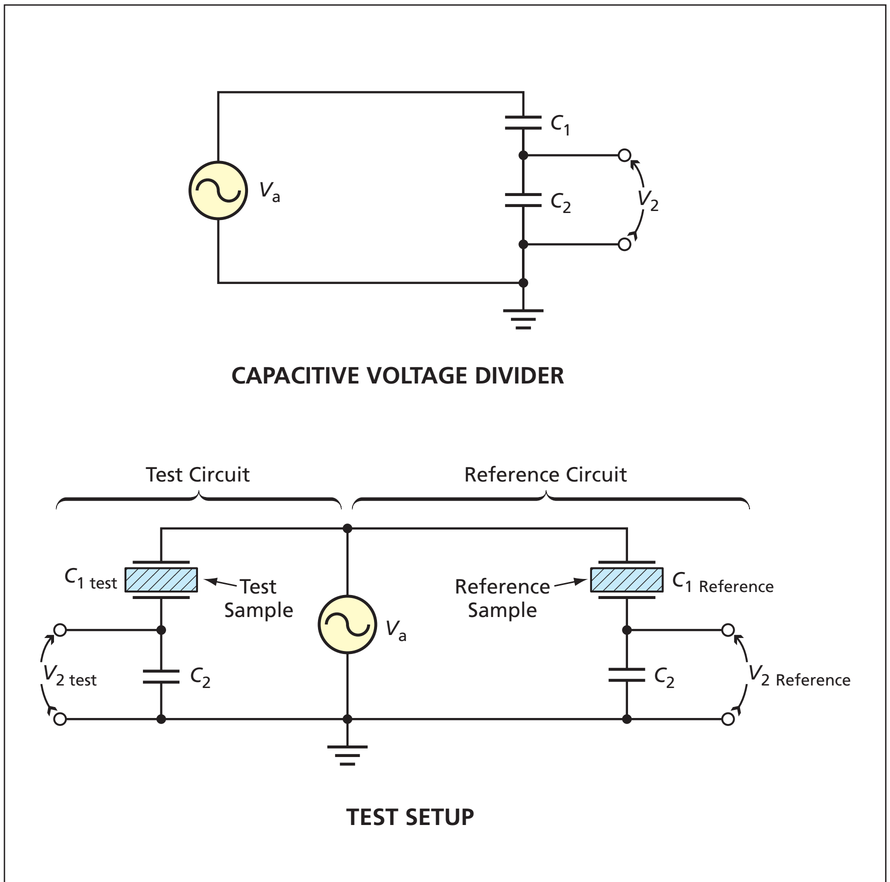
KSC-12572



The **Ratio Between the Permittivities** of the test and reference samples is closely approximated by $V_{2\text{test}}/V_{2\text{reference}}$, as long as the requirements stated in the text are satisfied. For the sake of simplicity, the guard electrodes and associated amplifier circuitry are omitted from the diagrams.