# VOLUME RESISTIVITY AND PERMITIVITY OF SOLID DIELECTRICS; CASE STUDY HOW TO DETERMINE THE EFFECTIVE AREA OF MEASUREMENT ELECTRODE

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*Abstract*
*Presented is how to determine the effective area of the measurement electrode during the calculation of volume resistivity and permitivity as a result of measurements in three electrode system. Errors are usually associated with this determination. But the presented analysis will help to correct the anomalis. The values of these errays are presently in a graphical manner as a guide. It is shown taht the factor of the measurement electrode extension at the electrical permitivity measurement also depends on electrical permitivity.*

**Keywords**: Resistivity, permittivity, Solid dielectrics, measurement, electrode.

## INTRODUCTION
The determination of the volume resistivity and electrical permittivity of solid dielectric and materials are usually carried out by an indirect method (Lisowski, 2004).

As a result, the tested sample is placed between the electrodes which together with the sample form a capacitor and then the capacitance of the capacitor is measured or the volume resistivity is measured the standard for the measurement of these parameters are in accordance with the IEC 60093. But recently, using the thin film technology or Nanotechnology, silver which is a very thin metal electrode are employed. These electrodes provide the resistivity and permitivity measurements with the smallest errors due to their contact with the dielectric. Usually, the measurements with taht plates are made using the three-electrode system (Lisowski, 2004).

The volume resistivity, σv of flat samples is given by

$$\rho_v = R_v \frac{A}{h} ---------- \{1\}$$

Where is the volume resistance, A is the effective area of the measurement electrode, and h is the sample thickness.

The relative permittivity is calculated using,

$$\varepsilon_r = \frac{C_x}{C_0} ------------ \{2\}$$

where $C_x$ is the capacitance between the measurement and voltage electrodes, $C_0$ is the equivalent geometric capacitance of the capacitor between the same electrodes, when the dielectric is in vacuum.

For the flat electrodes with guarded electrode

$$C_0 = \varepsilon_0 \frac{A}{t} ------------ \{3\}$$

The effective area of the measurement electrode A is always larger than its geanetrical area due to increase of the electric field at the edges of the measuring electrode (see fig 1 below)

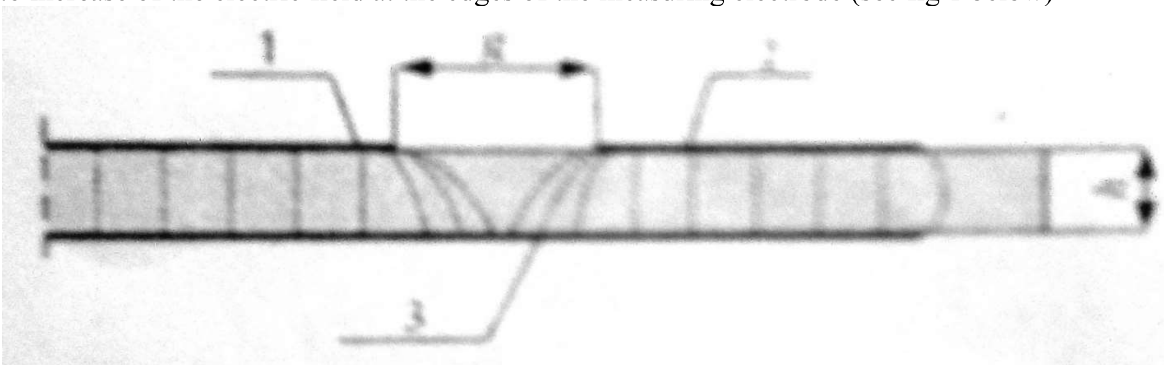

Fig 1.Distribution of electric field in volume of electric sample in the three electrode system.

Electrodes

1. Measurements (guarded),
2. Guard,
3. Voltage (unguarded)

Usually in practice and very often a half of the gap width (g/2) is added to the radius of the circular guarded electrode, i.e. the addition of the gap width g to its diameter d. In the same vein, the gap width g is added to each dimension of the rectangular electrode and to the length of the cylindrical electrode (Von Hippei, 2017).

These assumptions relating to the measurements of solid dielectrics were made in the international standard IEC 60093 But ASTM D 150 standard stated taht for the determination of the effective area of the electrode one should not use an increase of the border of guarded electrode equal to g/2, but instead.

$$\frac{g}{2} - \emptyset - - - - - - - - - - - - \{4\}$$

$$\emptyset = \frac{2t}{\pi} lncosh\left(\frac{\pi}{4}\frac{g}{t}\right) - - - - - - - - - - - \{5\}$$

The correction of the gap g can also be written in the form.

$$g\left(1 - \frac{2\emptyset}{g}\right) = Bg - - - - - - - - - - - - - \{6\}$$

in which ;

$$B = 1 - \frac{4}{\pi}\frac{t}{g} lncosh\left(\frac{\pi}{4}\frac{g}{t}\right) - - - - - - - - - - \{7\}$$

is the factor which is determining the increase of the spreading margin of the guarded electrode (Hamburger, 2018).

The equation (7) is correct for the calculation of the resistivity and also the permittivity on condition that the permittivity of the sample $\varepsilon = \varepsilon_r \varepsilon_0$is much larger than the permitivity of caccum $\varepsilon_0$

In practice, it is convenient to use a graphical form of this relation (Sihvola, and Kong, 2016).

Lisowski and Skopec (2009) showed that the factor B can be also expressed by the equation.

$$B = 1 - \frac{H-1}{\left(1-\frac{1}{\varepsilon_r}\right)(H+1)+\frac{\pi g H}{\varepsilon_r t(H-1)}} ----------\{8\}$$

Where H is determined using the formula

$$\pi\frac{g}{t} = H - \frac{1}{H} + 2lnH -------------\{9\}$$

It should be noted that equation (8)
Shows the factor B, and thus the effective area of the measurement electrode, depends not only on the radio g/t, but also on the permittivity.

For the volume resistivity is measured by placing the sample in a direct current electric field. For this field the pulsation w = 0 and the formula (8)
is converted to the following form (Lisowski, and Skopec (2009).

$$B_{w=0} = \frac{2}{H+1} -------------\{10\}$$

Whereas if $\varepsilon_r \to \infty$ the factor $B_{(\varepsilon_r \quad \infty)} = B_{w=0}$

According to equation (10), during the resistivity measurements the factor B is not dependent on the dielectric permittivity of the sample.
Figure 2 shows the graphical illustration of the factor B as determined from equation (8) as a function of the ratio of the gap width g to sample thickness t for different relative permittivity $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$
with decreasing of the permittivity $\varepsilon_r$the differences between these characteristics are becoming larger.

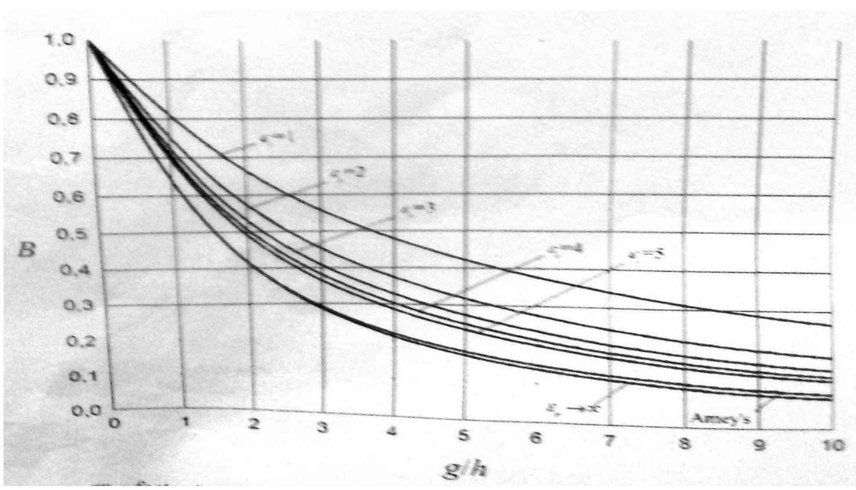


Fig 2.The factor B, calculated from the formula (8) for different relative Permittivities and from Amey's formula(7).

The results for different relative permittivity are shown graphically in figure 3.

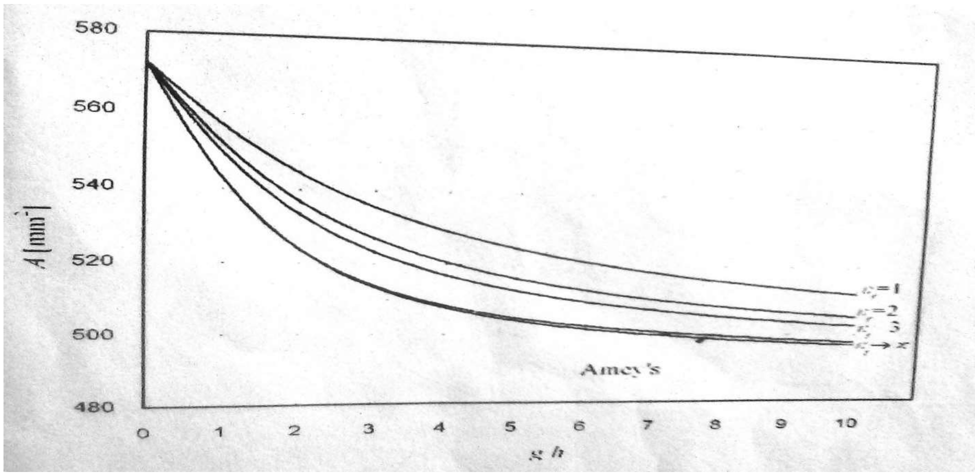


Fig 3. The effective area A of the measurement electrode calculated from Formula (11). Per g/h for different relative sample permitivities, where the factor B is calculated from relationship (8) and also from the Amey equation (7).

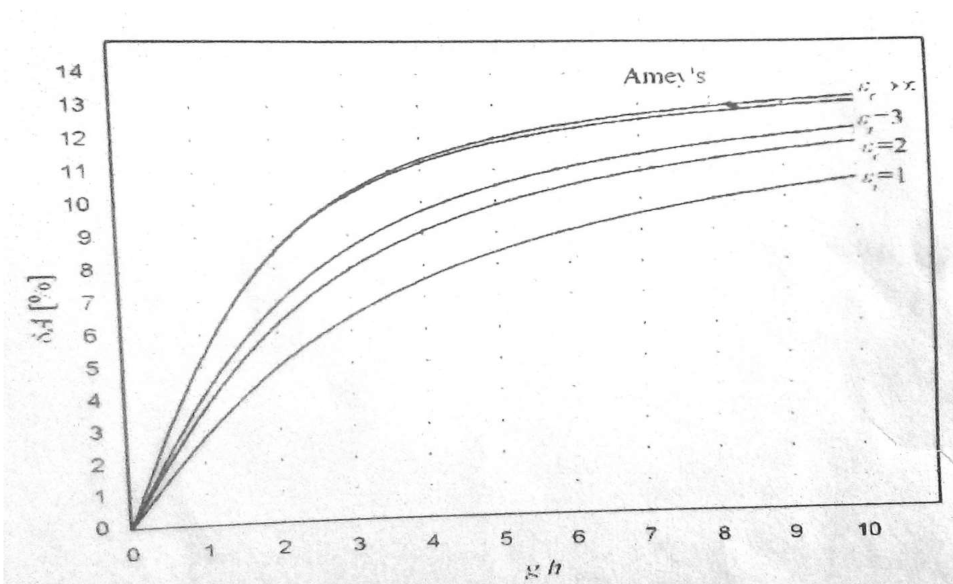


Fig 4. The relative calculation errors of the effective measurement electrode area caused by assuming the factor B=1

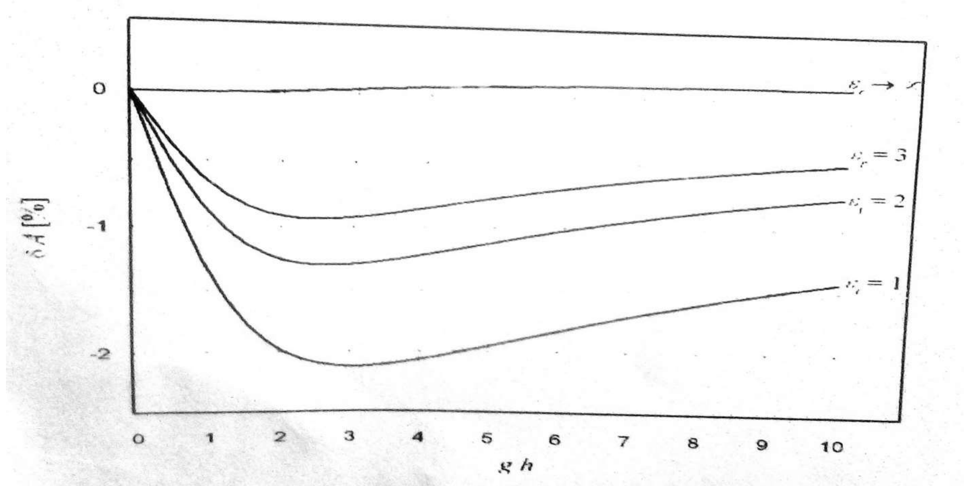


Fig 5. The relative calculation error of the effective area of the measurement electrode caused by the factor B determined by the Amey's equation (7).

**Interpretation of Results from graphs (Figures 2-5)**

Figure 2 shows the illustration of the factor B calculated from Amey's formula (Amey and Hamburger, 1999). The calculation analysis of effective area of the measurement electrode.

The effective area of the electrode for a circular electrode with the measurement electrode diameter, d, can be determined from

$$A = \frac{\pi(d + B_g)^2}{4} - - - - - - - - - - - - - - (11)$$

Its value highly depends on the factor B

As an example, suppose we analyses the effective area of the measurement electrode with diameter d = 25mm and width of the gap g =2mm.

Usually in the calculation of the effective area of the measurement electrode it is assumed that the factor B =1, i.e. the gap width g is added to the electrode diameter d. The relative error introduced by this assumption can be calculated from the relation.

$$\emptyset A = \frac{A_{B=1} - A_{B-1}}{A_{B=1}} x100\% - - - - - - - - - - - - -\{12\}$$

ØA = $A_{B=1}$ and $A_{B=1}$ are the effective areas of measuring electrode for B = 1 and B ≠1, determined using equation (8)

The results of calculation errors of the effective area of the measurement electrode assuming that the coefficient

B + 1 are shown graphically in figure 4.

For $\sum r \rightarrow \infty$ the relative error of the calculation of the effective area of measurement electrode, due to the assumption of B=1, reaches even up to 13% regardless of if the coefficient B was determined, using the Amey's relation (7) or equation (8).

If the calculation of the effective area is executed using B determined by Amey's relation (7) instead of the equation (8), the relative error of this calculation.

$$\emptyset A = \frac{A_{B(Amey)} - A_{B(8)}}{A_{B(Amey)}} x100\% ------------\{13\}$$

Where $A_B$(Amey) and $A_B$ (8) are the effective areas of measurement electrode for B determined by the Amey's formula (7) and B shown graphically in figure 5.
In figure 5, It can be seen that the maximum relative error of the calculation of the effective area of measurement electrode is 1.5%.

**Conclusion**
The effective area of the measurement electrode subjected to a flat sample, guarded by the circular electrode, formula (11). In the same vein, during the calculations of the effective area of rectangular or cylindrical electrodes, Bg should be added to the geometric dimension.

Factor B, which takes into account the enlargement of the effective area of the measurement electrode during the calculation of the volume resistivity, should be determined using equation (7) or (10), and during the calculation of the permittivity-using equation (8), wherein the coefficient H should be evaluated using equation (9). It should be noted that the coefficient B depends on the value of the permittivity during the permittivity measurement. It was also observed that the Amey's formula, commonly used to calculate the effective area of the measurement electrode during the measurements of low permittivity, can cause several percentage of measuring errors.

However, the biggest errors, over 10% can occur when the factor B =1 was assumed.

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