Bioelectromagnetics 5: 447–450 (1984)

Brief Communication

Calibration of Flat 60-Hz Electric Field Probes

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The influence of nearby ground planes, perturbation of surface charge distributions, and fringing fields on the electric field between parallel plates are characterized to define a parallel plate system that can be used to calibrate flat 60-Hz electric field probes.

Key words: calibration, electric field, ELF, instrumentation, measurement

Measurement of the 60-Hz electric field strength at the surface of a conducting electrode (eg, the bottom plate of a parallel plate exposure system for biological studies) is readily performed with a flat probe and an operational amplifier-voltmeter detector circuit [Kaune, 1978; Stern et al, 1983]. While information is available for calibration of electric field strength meters used for measurements at points between parallel plates [IEEE, 1978], no guidance currently exists for the flat probe-type fieldmeter. This communication describes a parallel plate apparatus that will produce a field whose strength is known with an uncertainty of less than 0.5% for calibration of flat electric field probes. The dimensions of the apparatus are specified in terms of the side dimension of a square probe which is to be calibrated. Circular probes may also be calibrated by using the diameter as the reference dimension.

Regions of nearly uniform electric field strength of known magnitude can be produced with a parallel plate system provided that the spacing of the plates, relative to the plate dimensions, is sufficiently small. The uniform field value, E_o, is given by V/t, where V is the applied potential difference between the plates and t is the plate spacing. The magnitude of the field at the plate surfaces of semi-infinite plates can be theoretically determined [Morse and Feshbach, 1953] and calculations show that the field is within 0.1% of the uniform value at a distance of one plate spacing from the edge. The edge effect due to four edges of a finite, square parallel plate system can be estimated by the principle of superposition. These results are valid in the absence of perturbations due to nearby grounded objects or planes, interaction between a field probe located on the bottom plate and the surface charge distribution on the top plate,

Received for review March 30, 1984; revision received June 15, 1984.

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Published by Alan R. Liss, Inc., 1984.

and the influence of the high voltage leads to the plates. These possible sources of field perturbation are examined for the case of one plate at ground potential.

The effect of nearby ground planes on the field strength at the surface of a grounded plate of a parallel plate system 1 × 1 m with a 0.18-m spacing between the plates was examined with a flat probe with dimensions 8.5 cm × 8.5 cm × 0.16 cm thick. A guard band 0.5 cm wide reduced the field-sensing area to 7.5 cm × 7.5 cm. In order to define the parallel plate spacing more precisely, the parallel plates were made from 0.95-cm-thick aluminum plate with surfaces that had been milled flat. The top plate was energized with an autotransformer-transformer combination. A line conditioner was used to stabilize the line voltage. Measurements of the 60-Hz electric field strength as a function of distance, d, between the field probe edge and one of the edges of the bottom plate were made in the presence of a single vertical ground plane, 1 m × 1 m, that was located two plate spacings (0.36 m) away from the edge of the parallel plates. The inset in Figure 1 shows the geometry of the parallel plates, probe, and vertical ground plane. Figure 1 also shows the change in field strength, in percent, as the normalized distance, d/t, is varied.

The decrease in field strength, which is largely due to the vertical ground plane near one edge of the parallel plates, is near 0.64% when d is equal to one plate spacing. In the absence of a nearby perturbing ground plane, the field strength would increase slightly relative to E_o [IEEE, 1978].

The effect on field strength due to four edges of a parallel plate system can be estimated by the principle of superposition for the case where the distance between the probe and each edge of the bottom plate is the same. Assuming the presence of

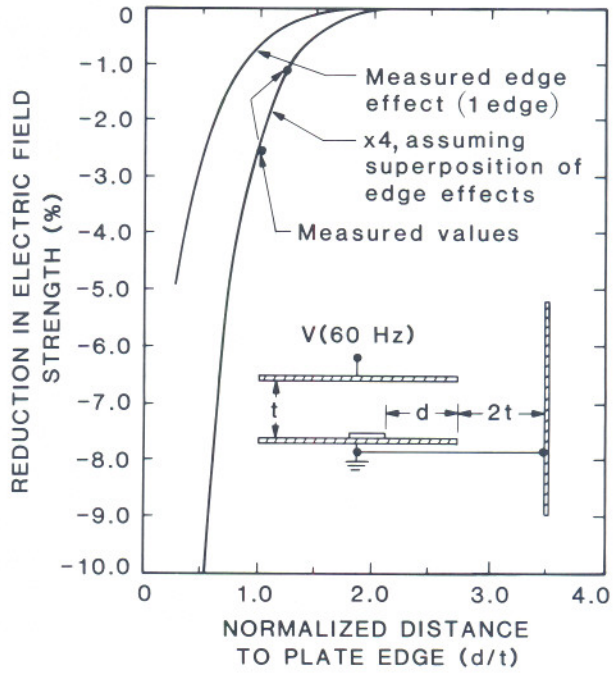

Fig. 1. Reduction in field strength at surface of grounded plate due to presence of nearby ground plane. The size of the data points reflects the uncertainty associated with the measured values.

vertical ground planes two plate spacings away from each side of the parallel plates, the measured reductions in field strength due to a single edge and vertical ground plane in Figure 1 are multiplied by four. These results are also shown in Figure 1 with the curve designated by $\times 4$.

The curve, assuming superposition of edge effects, was checked experimentally at two points with a smaller 46 $\times$ 46 cm parallel plate system with variable spacing. With the probe centrally located on the bottom plate, field strength measurements were obtained for 18-cm and 15-cm plate spacings. That is, the probe edges were near 1 and 1.2 plate spacings away from the edges of the bottom plate. Four vertical ground planes were located two plate-spacings away from the parallel plates during each measurement. These field strength measurements were compared with field values obtained with the probe located at the center of the larger parallel plates with 18-cm and 15-cm spacings. The reductions, in percent, are plotted in Figure 1. Good agreement is found with the estimated values assuming superposition of edge effects. Two data points in Figure 1 have been corrected for a small perturbation due to the presence of the high voltage lead and is discussed below.

In the absence of other perturbations, the superposition results in Figure 1 indicate that an electric field that is within 0.25% of the theoretical uniform field value V/t can be produced if the distances between the flat probe edges and the edges of the bottom plate are twice the parallel-plate spacing and if there are no ground planes closer than two plate spacings away. This result also assumes that the probe has a narrow guard band (ie, width is $\sim$6% of side dimension). A proportionally larger guard band or ground planes further than two plate spacings should reduce the edge effects. A choice was made to use two plate spacings as the distance between the parallel plates and nearby ground planes (and not a larger distance) because it appears to be a spacing that can be readily established or exceeded in most laboratories.

Because of the thickness of flat probes, the electric field in the vicinity of the probe will be perturbed. If the upper (energized) plate of a parallel plate system used for calibration of the probe is sufficiently close to the lower (grounded) plate, the surface charge distribution on the upper plate will be modified by this perturbation. Such an effect increases the field strength at the surface of the probe [Kotter and Misakian, 1977].

Measurements of the same uniform electric field V/t were performed with a 8.5 $\times$ 8.5 $\times$ 0.3 cm thick probe centrally located in the 1 $\times$ 1 m parallel plate system with different plate spacings to determine when the interaction between the probe and the upper plate became negligible. Figure 2 shows the field strength, E, normalized to the field strength observed when the spacing was 0.18 m (taken to be the uniform value, E_o) as a function of plate spacing normalized by the dimension of the probe (8.5 cm). The error bars shown in Figure 2 reflect uncertainties in the measurement of the electrode voltage ($<$0.05%) and the parallel plate spacing ($<$0.3% for 5 cm spacing, and less for larger spacing). The interaction between the top plate and a probe with a thickness that is 3.5% of its side dimension leads to a field enhancement at the probe surface that is less than 0.25% when the parallel plate spacing is greater than one and one-half times the side dimension of the probe (Fig. 2). Similar measurements with a probe of half the thickness led to enhanced fields at the probe surface which were about half as large as those shown in Figure 2.

The possibility of the calibration field being affected by the presence of the high voltage lead to the upper plate of the parallel plate system was examined for a number

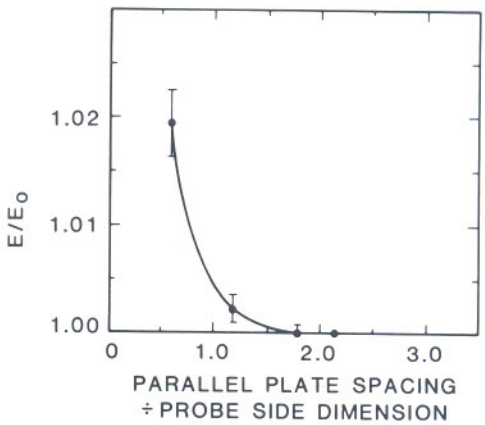

Fig. 2. Perturbation of electric field strength at probe surface due to interaction between probe and surface charge distribution on energized plate.

of parallel plate spacings. The procedure used was to compare field strength measurements obtained with a flat probe 8.5 × 8.5 × 0.16 cm thick when one high voltage lead was connected to the upper plate with those of measurements obtained with two leads connected. The influence from the leads was considered negligible if there was no difference between measurements. No contribution to the field could be detected (within 0.04%) when the distance between the probe and plate edges was twice the plate spacing.

An electric field that is within 0.5% of the theoretical uniform field value V/t can be established for a flat probe using a parallel plate system, provided that the spacing of the plates is more than 1.5 times the side dimension of the probe and the distance between the probe edges and plate edges is no less than two plate spacings (ie, three times the probe side dimension). These results are valid for a square probe with 6% or *greater* guard bandwidth and a thickness that is no more than 3.5% of the probe's side dimension. All nearby ground planes should be at least two plate spacings away from the parallel plates. Uncertainties in the values of V and t will add to the 0.5%.

ACKNOWLEDGMENTS

This work was supported by the Department of Energy.

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