ELECTROSTATIC PAPERHOLDER

Photographers, draughtsmen, compositors, lithographers, artistic as well as technical designers, and, of course, architects use drafting tables which should allow quick and safe exchanging, positioning and fixing of large sheets of paper. For this purpose, an electrostatic paperholder has significant advantages over clip-on systems or bits of drafting tape.

A wide range of equipment is currently available for putting graphics information on paper. Such equipment includes printers, plotters, X-Y and X-t recorders. In all of these, it is essential that a pen device or printer head can move with respect to the paper surface. In most cases, paper is held on a roll, which is rotated to achieve movement in the Y-direction, while a carriage is used to achieve movement of the roll, or the pen, in the X-direction. There are, however, also systems in which the paper is held flat and secured on the working table, while the pen is moved across it in both directions. This arrangement is essentially identical to that of the well-known drafting table, for which the electrostatic paperholder was developed about 20 years ago. The current trend in plotter design, however, is clearly towards the rotating paper roll.

To prevent the electrostatic paperholder falling into oblivion, this article aims at providing essential information on the operation, designing and building of this drafting aid.

Theory of operation

The general structure of the electrostatic paperholder is shown diagrammatically in Fig. 1. In principle, the construction is relatively simple, but some theoretical knowledge is required for explaining and understanding the basic operation and the effect of all parameters involved.

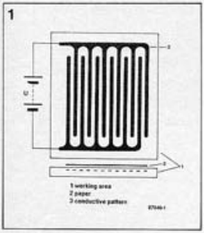

Fig. 1. Basic structure of the electrostatic paperholder.

The system can be analyzed in two ways. One is based on the theory of electrical fields. This includes the possible, but important, role of a large number of side-effects that other models fail to take into account.

The second way of analyzing the electrostatic paperholder is an essentially qualitative approach which has the advantage of being more illustrative and better comprehensible than the theory of electrical fields.

Figure 2 shows a schematic representation of a part of the electrostatic paperholder. The diagram shows voltage U present between two tracks of the conductive pattern. This voltage causes an electric field, E, between the tracks. The field strength is directly proportional to the voltage applied. Lines of force will cross the working area, but also extend beyond this, traversing the paper sheet. This will result in a certain degree of polarization of the paper due to dielectrical shift, which, in turn, is explained by the relative permittivity of paper, which is about 3 (ε_r = dielectric constant).

The force between paper and working table is then best understood in terms of a force between two charges: one is the apparent charge caused by polarization of the paper (proportional to field strength E and, therefore, voltage U), the other the charge on the electrodes of the working table (also proportional to U, and, in addition, to the capacitance). Since voltage U determines both the degree of paper polarization and the amount of charge on the electrodes, it can be safely assumed that the force is proportional to the square of U. In addition, the force between two charges is inversely proportional to the square of the distance, which means that the thickness of the insulating layer above the electrodes is an important factor. Also note that the number of lines of force traversing the paper decreases with an increase in the distance between paper and electrodes.

The above model allows simple deducing of a number of additional parameters that determine the adhesive force between paper and working table.

Relative humidity of the paper is an important parameter. Relative permittivity of water is as high as 70, caused by the dipole moments of individual water molecules. As a result, dielectrical shift in paper with high relative humidity will be considerable, causing increased adhesive force. It should be noted, however, that humid paper has conductive properties, which are augmented by impurities in water. Since electric field strength is effectively cancelled in a conductor, there will be no force at all on the paper when this is humid. In practice, it has evolved that a relative humidity of 40-50% is optimum for most applications.

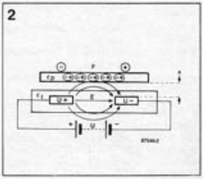

Fig. 2. The electric field causes dielectric shift in the paper, resulting in a force between paper and electrodes.

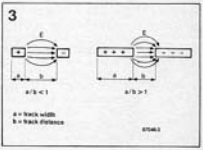

Fig. 3. The pattern of the lines of force is determined by the geometry of the track pattern.

A further important parameter to consider is the geometery of the electrode pattern, since this determines the pattern of the lines of force. Tracks whose width is small relative to the track-to-track distance cause the field to become so narrow that it does not act on the paper. A higher width/distance ratio gives a more favourable pattern of the lines of force (see Fig. 3). A ratio of slightly more than 2 was found to give best results in practice.

The final parameter to consider is the permittivity of the working table material. High relative permittivity results in high inter-electrode capacitance and, therefore, a high amount of electrode charge ($Q = UC$). Hence, adhesive force is also greater.

The curves in the graph of Fig. 4 were obtained from experiments. The y-axis shows force per unit of area at a certain voltage and electrode distance. Increasing this distance results in strong vertical shrinking of the curves. Increasing the voltage by a certain factor compresses the vertical scale with the square of the factor.

An experiment

Observing the above criteria, the following conditions should be met for obtaining reasonable adhesive force on the paper:

- Voltage should be as high as possible without causing arcing between tracks.
- Paper-electrode distance should be as small as possible.
- Relative permittivity of the working table should be high.
- Ratio of track width to track distance should be greater than 2.

A further important consideration not mentioned so far is safety. Clearly, the first two of the above conditions conflict in respect of safety. For an efficiently operating paperholder, paper-electrode distance should be of the order of hundredths of a millimeter, or one tenth at the most. A voltage of 1 kV already requires special properties of the upper layer of the working table in respect of insulation. Standard epoxy PCB material is unsuitable here because it is too thick. Considerable adhesive force is obtained when the paper is laid direct onto the copper tracks, but audible corona effects via the paper will be observed ($U = 2.5$ kV; track distance: 2.5 mm). Polycarbonate foil as used for *Elektor Electronics* adhesive front panels ensures sufficient electrical insulation, but has the disadvantage of reducing the electrostatic effect by increasing the electrode-paper distance. Better results should be obtainable with much thinner foil as used for covering model airplanes. This material is simple to secure on surfaces with the aid of a flat-iron, but the insulating properties would have to be checked in practice.

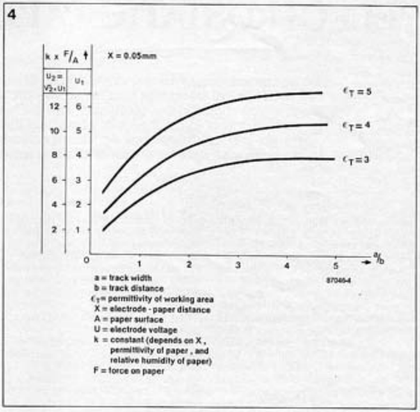

Fig. 4. Force per unit of area as a function of the ratio of track thickness to track distance, with relative permittivity of the working area as a parameter. Force is a square function of the voltage.

Practical suggestions

The drawing of Fig. 5 shows a suggested structure of an electrostatic paperholder. Ordinary PC board material can be used as the base material. The track pattern is readily made with the aid of rub-off artwork transfers. A complete raster pattern on one sheet (track width: 3 mm; track distance: 1.5 mm) is rubbed off in one go. Alternate tracks are then shortened, and protruding tracks are connected at both sides. After etching, the panel can be smoothed with a thin layer of potting compound (car body repair material is suitable here). After this has stiffened, the layer is cleaned, polished, and covered in model aircraft foil (Fig. 5).

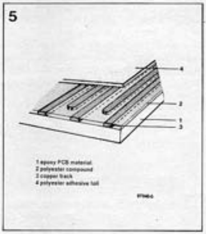

Fig. 5. Structure of a home-made paperholder to traditional design.

The high voltage source for the paperholder need not supply current because leakage current in the etched panel will be negligible. Figure 6 shows a suggested circuit for the high voltage cascade. The use of a mains transformer is obligatory. If a 1:1 safety transformer is not available, a step-down type (240 V/117 V) may be used with the corresponding number of cascade sections added. The actual voltage required depends largely on the foil thickness, so that the high voltage source is best constructed in a step by step manner by adding as many cascade sections as required. Commercially available electrostatic paperholders usually operate at 1 kV.

A prototype of the paperholder required 2...3 kV (track width 3 mm; track distance 1.5 mm; foil thickness approx. 0.05 mm). The circuit diagram of the voltage source used is shown in Fig. 6. Four cascade sections in each arm were

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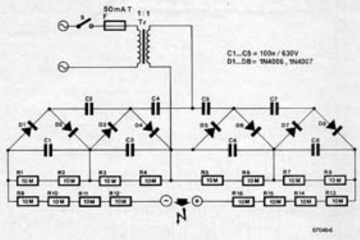

Fig. 6. Symmetrical high voltage supply for the paperholder.

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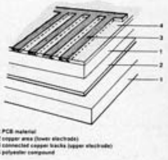

Fig. 7. Alternative construction of a paperholder, which is esentially a PCB sandwich. The HV electrode is formed by the unetched copper surface on the lower circuit board. The upper electrode is earthed.

used to give an output of 8×330 V = 2640 V. The resistors fitted in parallel with the high-voltage capacitors ensure that the paper is released within 2 to 3 seconds after switching off. The high-value series resistors function as current limiters to safeguard users from lethal currents when the electrodes are accidentally touched. Every precaution should be taken to prevent this happening, bearing in mind that even small currents can be lethal when carried in or near the heart area.

An alternative

The electrostatic effect of the previously suggested paperholder is still relatively small, notably when using certain types of photographically sensitive or other PVC-based paper. An alternative paperholder was, therefore, designed and studied to overcome this defiency. The new structure is shown in Fig. 7: the working surface is essentially composed of double-sided PCB material. It is, however, recommended to use two separate sheets of single-sided material, since this automatically ensures insulation of the lower side. The lower electrode is simply a large conductive surface. The top side carries a fine pattern of interconnected tracks (a checkered pattern is also suitable) which forms the complementary electrode. Paper laid on the top surface will be at the potential of the upper electrode. The function of the etched pattern is to ensure that force is evenly distributed over the entire sheet. Adhesion is not obtained by dielectric shift in the paper, but as a result of the force between the charge transferred onto the paper by the upper electrode, and the charge on the lower electrode. There is no dielectric shift in the paper because this lies in an area of one potential only. This set-up has advantages in respect of safety and construction, because the upper electrode can be connected to earth, while the high voltage is only present well-insulated at the lower side.

The circuit diagram of Fig. 8 shows that the cascade used for the alternative paperholder is asymmetrical to prevent high voltages between the primary and secondary winding of the transformer. A 5-stage HV cascade was used to obtain an output of about 1700 V. Figure 8 also shows the use of two small low-voltage transformers whose secondary windings are connected to act as a 1:1 safety transformer.

A disadvantage of the alternative paperholder described is the need for the paper to be in galvanic contact with the upper electrode. This means a higher risk of oxidation of the copper tracks, unless these are tinned. The upper side of the work area can be smoothed with a thin layer of potting compound as discussed earlier.

It is hoped that this article provides a basis for further experiments in building an electrostatic paperholder of the required size. Your practical notes and comments are appreciated!

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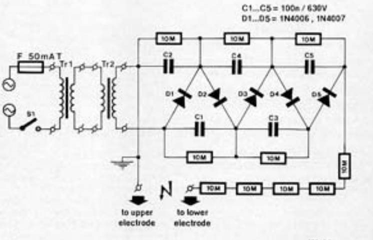

Fig. 8. Suggested HV source for the alternative paperholder. U_{out} is approximately 1700 VDC at an input of 240 VAC.