# A New 3D Electroplating Simulation and Design Tool

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Electroplating process energy and material costs are very important considerations in product manufacturing. The most important plating criteria, however, are quality and plated uniformity of the deposited metals. Simulation tools can help to obtain better plating results.

New plating simulation tools are now available that will run on PC/Windows computers and can point the way to optimizing many common electroplating processes. Software packages are available that are versatile and user-friendly. These tools have been designed to optimize electroplating cells and racks. An accurate analysis is required to determine distribution of deposited thickness, current densities, and electrode potentials. A good plating simulation tool can help an engineering team find the most reliable rack configuration based on the geometrical description of rack, the parts to be plated and from calculation of the electrochemical properties of the process being studied.

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The design of an electroplating rack requires many preliminary steps such as: the choice of the electrolyte, and the location, shape and number of electrodes, masks and current thieves. These parameters affect deposit thickness and plating distribution. Preliminary steps taken to optimize a plating process might be very time consuming if they are performed in a trial-and-error fashion, i.e. plating parts, measuring thickness, plating again etc. If those trial-and-error steps can be simulated accurately, large gains can be made in overall plating cost reduction and the time-to-market of new part designs. Plating parts in actual production requires that several parts be placed in the same electrolytic plating tank. The primary difficulty is in obtaining uniform deposits on each part and from part to part to satisfy plating thickness tolerances assigned by the plating performance specification. We must often deposit more metal on a given area to achieve the necessary minimum plating thickness in another area. This not only increases overall cost but may also require additional remedies in areas where there is an excess of plated metal.

Therefore, effective electrolytic plating thickness simulation helps plating industries to design the most appropriate rack and tools to produce the best deposit uniformity on each part. Many industrial electroplating applications have been optimized by the use of new plating simulation software. The software is based on an original numerical method called Boundary Element Analysis. For the last 20 years the reliability of this kind of engineering tool and the accuracy of the results achieved have been proven by the many industrial applications[1-2].

## 1. Mathematical modeling

The electrolytic domain $\Omega$ is bounded by $\Gamma=\Gamma_A\cup\Gamma_C\cup\Gamma_R$. The boundary is constituted by insulating part $\Gamma_R$, anodic boundary $\Gamma_A$ and cathodic boundary $\Gamma_C$ (figure 1). In the electrolytic domain $\Omega$ the electrical potential is constructed with equation (1) describing ionic migration. Boundary conditions choice is: in the electrolyte $\Omega$ equation (5) links potential $u$ and current density $j$, on insulating part $\Gamma_R$ Zero current value is applied (2), on cathodic boundary $\Gamma_C$ and on anodic boundary $\Gamma_A$ Experimental polarization laws (3) (4) are assigned. These laws describe the kinetics of the reaction at the electrode[3-4].

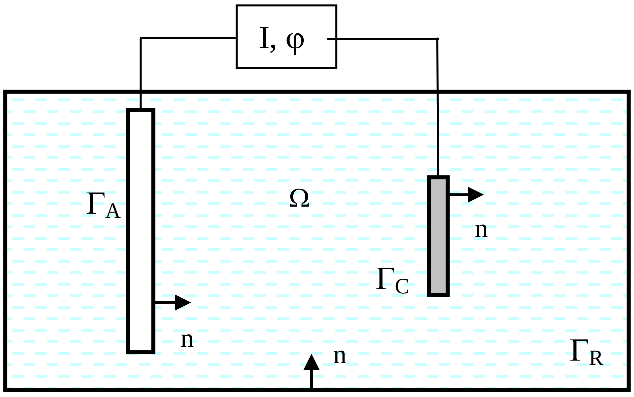


*Figure 1 - Representation of an electrochemical system.*

The problem (P1) of electrochemical plating is described by: Find potential $u(x)$ in $\Omega$ for a known potential difference $\varphi\neq0$ such as[5-6]:

$$
\text{(P1)} \quad \begin{cases}
\operatorname{div}(-\sigma \cdot \operatorname{grad} u(x)) = 0 & \text{in } \Omega \quad (1) \\
\sigma \dfrac{\partial u}{\partial n} = 0 & \text{on } \Gamma_R \quad (2) \\
\sigma \dfrac{\partial u}{\partial n} = f\big(u(x)\big) & \text{on } \Gamma_C \quad (3) \\
-\sigma \dfrac{\partial u}{\partial n} = g\big(u(x) - \varphi\big) & \text{on } \Gamma_A \quad (4)
\end{cases}
$$

Current density vector is determined with local gradient of potential u(x) in the electrolytic domain $\Omega$ and is established with the Ohm's law (5). On each point x of the boundary $\Gamma$ the current density j(x) is described by equation (6).

$$
\begin{cases}
\vec{j} = -\sigma \cdot \operatorname{grad} u & (5) \\
j(x) = \vec{j} \cdot \vec{n} = -\sigma . \partial u / \partial n & (6)
\end{cases}
$$

Electrochemical behavior laws f and g are non linear, thus the system (P1) is also non linear. The problem is solved by the Boundary Element Analysis Method coupled with a Newton-Raphson technique.

Only electrolytic domain boundaries are modeled, and the integral formulation is written for each point x of submerged surfaces $\Gamma$,

$$
\begin{cases}
\forall x \in \Gamma \\
C(x)\, u(x) = -\int_\Gamma j^*(x, y)\, u(y)\, d\Gamma + \int_\Gamma j(y)\, u^*(x, y)\, d\Gamma
\end{cases}
\quad (7)
$$

$$
\begin{aligned}
C(x) &= 1/2 \ \text{ for } x \in \Gamma \ \text{ if tangent plane is continuous at point } x \\
&= \ 1 \ \text{ for } x \in \Omega
\end{aligned}
$$

where fundamental solutions of Laplace operator j* and u* depend only on the electrochemical characteristic $\sigma$ and on y and x respectively, the generic point and source point, and C is the free term coefficient. Physical variables j and u of the domain boundary are linked by boundary conditions (non-linear polarization laws). The boundary element anaylsis method is a mixed method that allows calculations of the unknown potentials u and current density j with the same accuracy. This is a specificity of the method itself.

At the generator the dual global quantities (current I and potential difference $\varphi$) are linked by a non-linear function (a generalised Ohm's law). The resolution of (P1) is not enough, so an algorithm has been developed, monitored by global current I. This current input value corresponds to the working current density advocated by a plating bath supplier. When the convergence is reached, the numerical electrochemical balance is adjusted to the industrial process balance. Hence, the current densities obtained are used to determine electrodeposits on the cathode with Faraday's law.

## 2. Model of a rack

The plating rack and other electroplating hardware (masks or shields) are then described by a graphical tool in a three-dimensional space. Interactive solid modeling, based on ACIS®, allows plating simulation of the complex geometry of the electroplating rack and the parts to be plated. It's the principal part of the simulation tool. The second feature is an electrolytic data manager composed of all the electrochemical characteristics needed to adequately simulate actual electrodeposition: electrolyte conductivity, cathodic and anodic polarization laws, cathodic efficiency law, properties of the deposited material, and the working current density.

The Figure 2 represents an industrial application studied for the French firm Electropoli.
The plating rack is configured for zinc electroplating treatment of pulleys. This particular example was used as a model to study the rack in order to optimize plating depositing thickness uniformity. The parts are pulleys, an automobile component with an exterior diameter of 95 mm (3.8 in.). The rack is constituted by a double framework of 216 pulleys.

The zinc electrolyte has been studied to determine its electrochemical properties and polarization laws have been identified to give the model real electrochemical behavior of its electrodes. The software's electrochemical data manager includes these properties, and from the geometry description of rack components (parts, anodes, current thieves and masks), a model has been prepared.

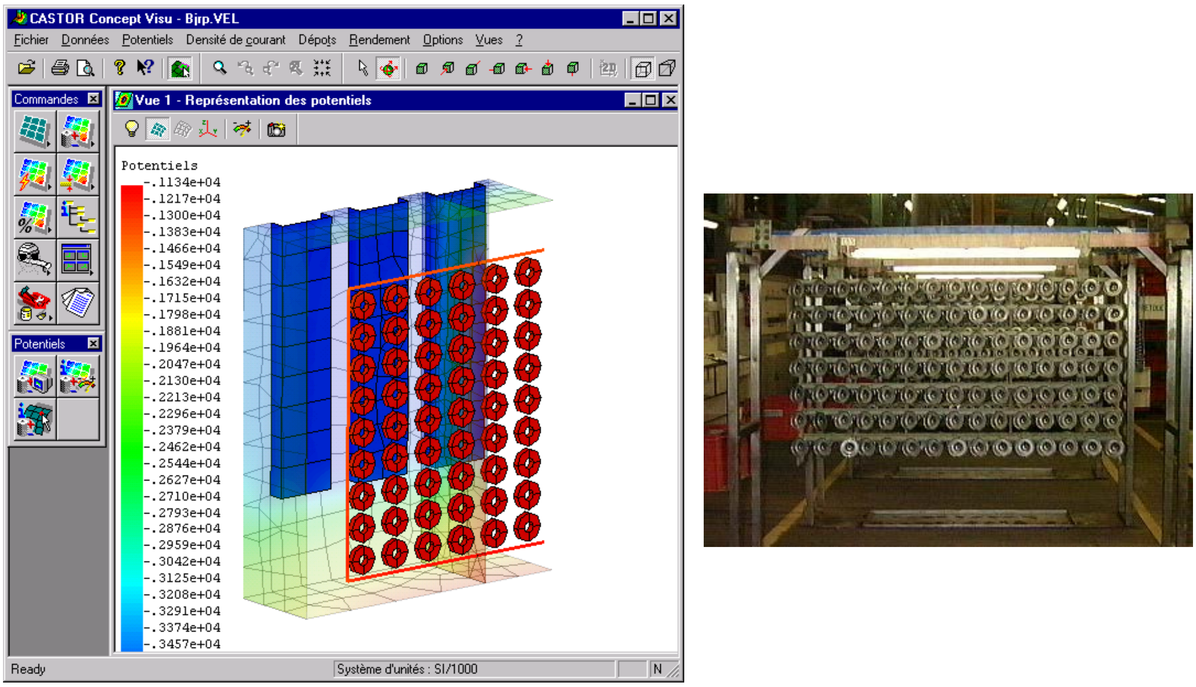


*Figure 2 - Modeling of zinc electroplating of pulleys - Electropoli installation.*

This model (figure 2) takes into account the complex geometry of the subject rack. After numerical analysis and electroplating simulation the simulated results are compared with the actual deposits (as measured X-ray fluorescence). Wherever plating thickness readings are taken on the rack, the simulated and actual deposited thicknesses measured are in good agreement.
The next step has been to optimise the deposits cartography by introducing insulating masks and current thieves. Several configurations have been studied to give appropriate configurations of the plating rack and masks or thieves.

## 3. Electroplating validation

### *3.1 Chromium electroplating for treatment of valves*

A second industrial application shows good correlation between the simulation tool and the measured plating deposits. The firm manufacturing the valves required a thorough study of their hard chrome plating operation. To fully optimize the manufacturing of the valves it was necessary to optimize the plating process. The distribution of hard chromium deposits must be uniform along each valve while maintaining low minimum deposit thickness tolerances.

The electrolyte is composed of hard chromium. The model and the simulation have been made on a framework of 112 valves where just the spindles must be cover with chromium. The model takes into account the complexity of the entire system including masks to channel current lines.

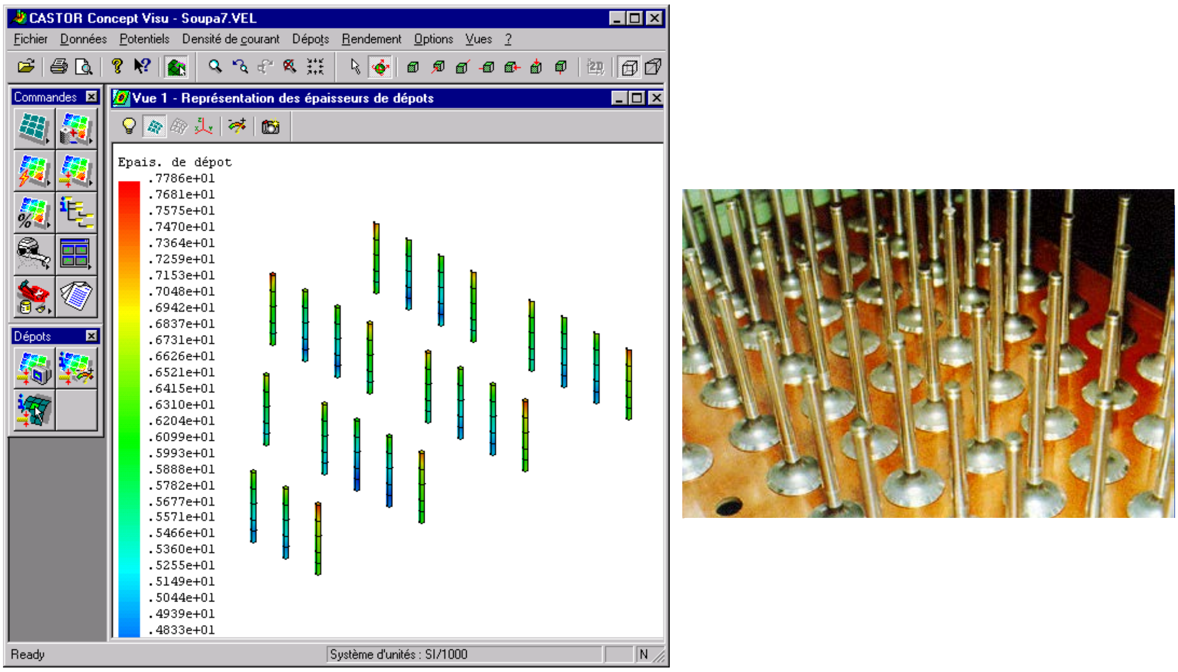


*Figure 3 - Visualization of deposit thicknesses on valve spindles*

The reading of actual deposits made by TRW are in good agreement with those calculated in the simulation, illustrated by Figure 4. The values represent the deposits average on the bottom and head of the valve.

| | Measurements | Calculation | % difference |
|---|---|---|---|
| Foot | 6.4µm (256µin.) | 6.8µm (272µin.) | 6 |
| Head | 4.8µm (192µin.) | 5.6µm (224µin.) | 16 |

*Figure 4 - Readings average on the valves spindles*

When the numerical model of the TRW rack has been validated by industrial plating thickness measurements, we have tried to optimize depositing thickness by changing locations of different rack components. A configuration was tested and satisfactorily implemented.

### *3.2 Zinc electroplating for plates treatment*

Another electroplating rack configuration change confirms the performance of the plating software. The firm MARQUET treats hundreds of small parts fitted together in 30 plates. These plates were modeled successfully and changes made to the plating configuration.

The manufacturer provided a rack whose configuration was described by the following parameters: location, shape and number of electrodes. In order to setup a new production line, it was important to determine by simulation a rack configuration resulting in the best possible deposit thickness uniformity. From this configuration we model several racks to optimize these parameters. We have chosen a model which gives, by simulation, the following depositing thickness visualization,

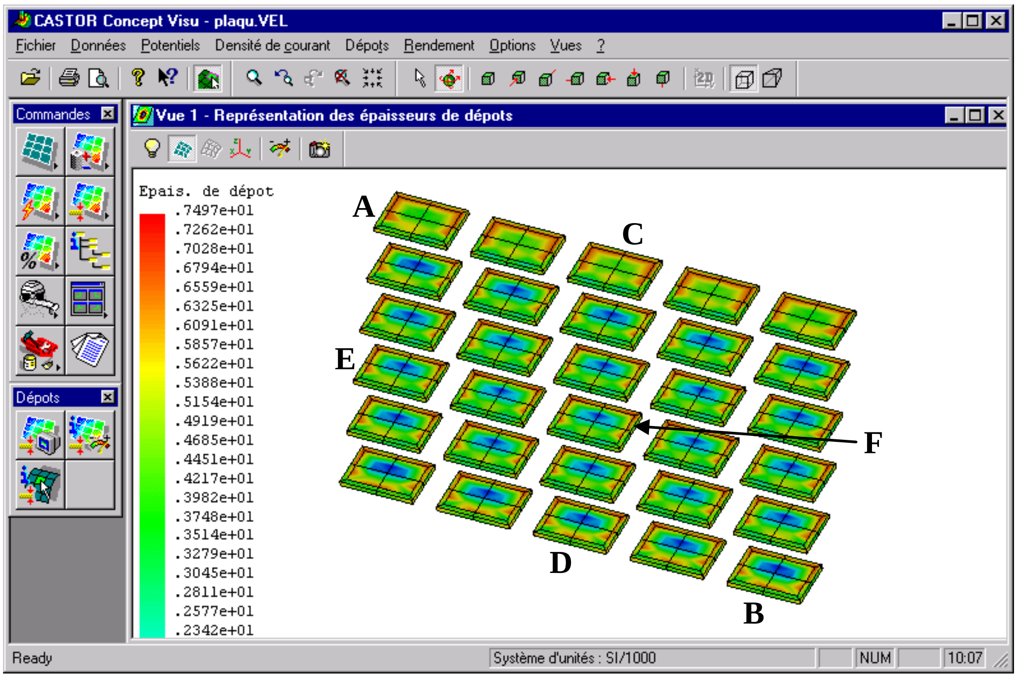


*Figure 5 -Display of optimized depositing thickness on plates.*

The colors display seems to be convenient. The deposit distribution is uniform. The workshop team makes measurements (X ray) on parts to study the deposits of six plates. Figure 5 shows the choice of the plates to compare the simulation results with those observed in the actual plating process. For each plate (ABCDEF) deposit measurements at 5 points have been compared to calculated deposits as illustrated in Figure 5.

The correlation between measured and simulated deposits is excellent. This further demonstrates the performance of plating engineering tools that simulate deposit thicknesses. We can notice in the Figure 6 there is deposit uniformity from part to part, and the industrial requirement is achieved.

This tank configuration will be used to setup a new production line. These preliminary steps taken with 3 dimensional plating simulation software have enabled choice of the optimum electrolyte and the position and dimensions of the different electrodes in the tank. Results of this zinc electroplating study have allowed the convenience of not taking into account the hundred of parts, but just the plates.

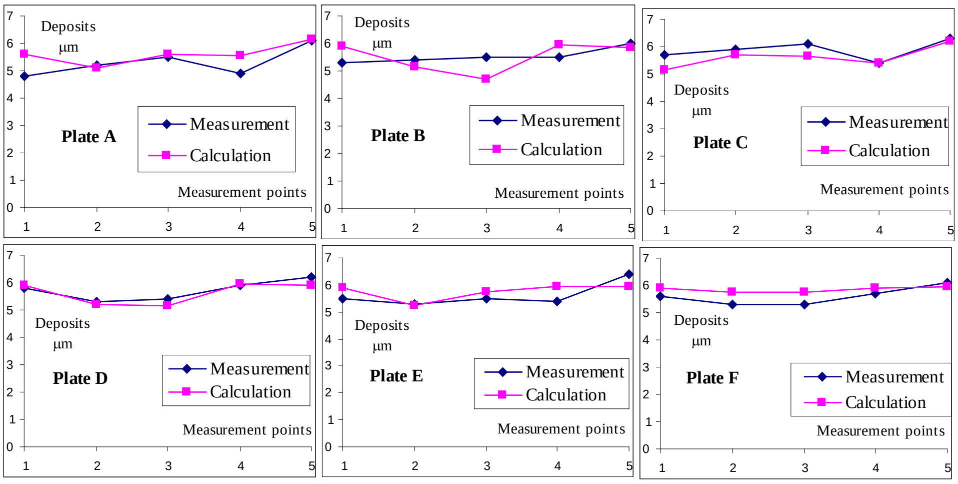


*Figure 6 - Comparison between measured and calculated deposits for 6 plates.*

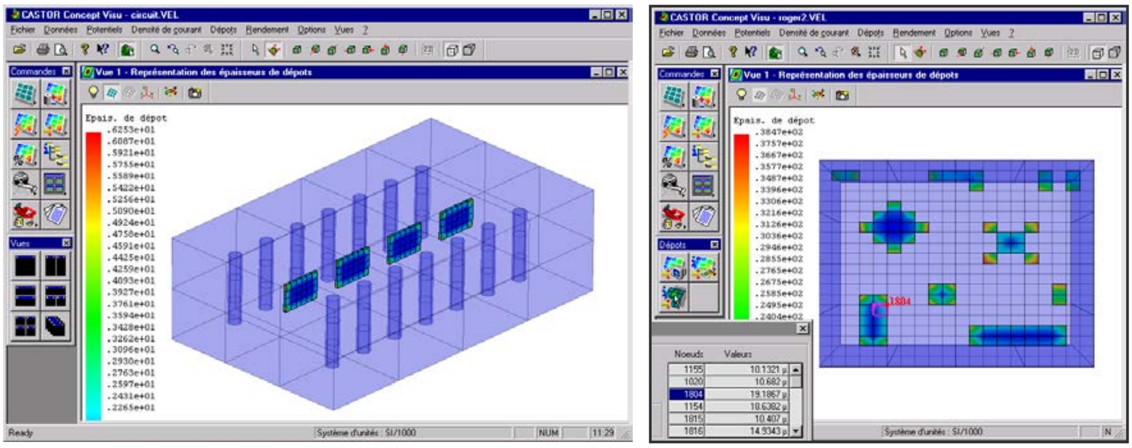
### *3.3 Copper electroplating for printed circuit boards*

Electroplating process energy, plating time and raw material costs are also very important in electroplating printed wiring boards but they are seldom given much consideration. The most important plating criteria are quality and more specifically, plated uniformity of the deposited metals. 3D electroplating simulation tools can help printed wiring board manufacturers to obtain dramatically better plating results.

The recent history of electroplating complex multilayer printed circuit boards, especially newer, more difficult-to-plate board designs, has been lackluster. Density of surface features such as SMT pads, fine line circuit traces and blind via holes make plating circuit boards with uniform electrodeposits a monumental challenge. Underplating of blind via holes can easily occur while simultaneously overplating other areas of the board and it is particularly difficult to understand and control the electrode potential of isolated traces or pads. It is not unusual to plate 2.0 to 2.75 mils of copper on some part of a printed circuit board to achieve a minimum plating thickness specification of 0.6 - 0.8 mils for blind vias and 0.8 – 1.0 mils for through-holes. 1.0 mil overall is usually the specification for plated copper.

When plating printed circuit boards, the "picture-frame" effect of the non-uniform plated deposits is as pronounced as in plating many flat objects. For printed circuit boards however, the negative consequences are much greater. Complex multilayer boards are generally overplated to such a degree that subsequent printed circuit manufacturing operations are negatively affected, e.g. resist stripping, solder mask coverage and assembly.

Non-uniform plating is not the only negative issue. Productivity is also significantly affected. The above mentioned plating deposit uniformity problems are commonly found plating in current density ranges of 10-15 a.s.f. It is well known to most electroplaters however, that conventional acid copper electrolytes made for printed circuit plating are easily capable of much higher current densities, e.g. 35-50 a.s.f.



| Noeuds | Valeurs |
|---|---|
| 1155 | 10.1321 µ |
| 1020 | 10.682 µ |
| 1804 | 19.1867 µ |
| 1154 | 18.6382 µ |
| 1815 | 10.407 µ |
| 1816 | 14.9343 µ |

*Figure 7 – Deposition of copper simulation on circuit boards  - Zoom on a circuit board*

New plating simulation software now available will run on conventional PC Windows 95/98/2000 and NT operating systems and can point the way to optimizing many common electroplating processes for printed circuit boards. The software is versatile and user-friendly. These new software tools have been specifically designed to optimize electroplating cells, plating racks and cathodes so that plating current can be focused where it's wanted and shielded from areas of a circuit board that would otherwise be overplated.

With better understanding of printed circuit board electrode potentials, as provided by circuit board design files, plating of circuit boards is expected to yield demonstrably better results. Sophisticated analyses and mathematical calculations are required to accurately simulate and determine circuit board electrode potentials, plating thickness distribution and optimum current densities. A good plating simulation tool can help an engineering team find the most reliable rack configuration based on the geometrical description of the rack, the parts to be plated and from calculation of the electrochemical properties of the process being studied.

## Conclusions

For a considerable time, technically advanced plating simulation software has been tested and successfully used in many electroplating applications. The results obtained by simulating the electroplating process have been in close agreement with measurements taken from production plating results. When the preliminary steps of plating cell design, cathode design and rack design are simulated numerically, the results of the simulation help to achieve optimum plating configurations. One of the principal objectives of a plating simulation tool is to design the most appropriate cell, rack and ancillary tools needed to repeatedly produce optimum plating deposit uniformity on the cathode.

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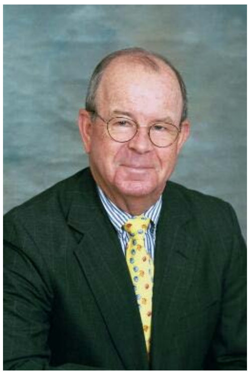

Roger Mouton founded EIMC, focusing on Advanced Plating Technologies and electroplating process development. He has experience in product and business development, sales, marketing and technical service in the electronics manufacturing and metal finishing industries. He has authored articles in Printed Circuit Fabrication, CircuiTree Magazine and The Board Authority, Metal Finishing Magazine and Plating and Surface Finishing Magazine. He holds a B.A. in Economics from Loyola University.
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