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Aging Analysis to Capture Long-Term Performance of Semiconductor Devices

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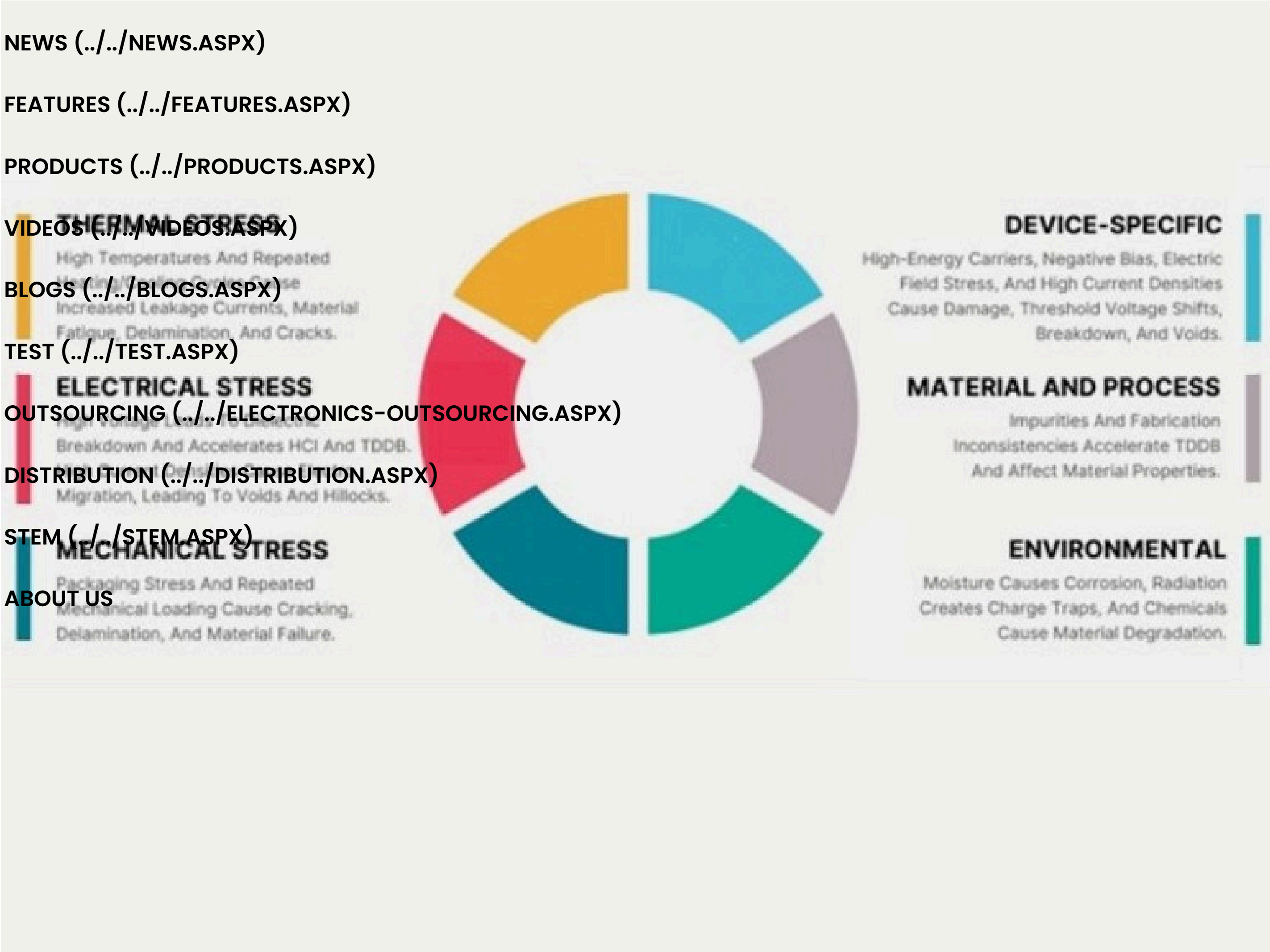

Figure 1: The various causes of semiconductor aging

Designing, manufacturing and mass-producing semiconductor products requires meticulous data collection and analysis. These steps ensure that the final product released to the market meets customer expectations, is defect-free and performs reliably throughout its anticipated lifespan.

To meet these high standards, new semiconductor products and technologies undergo a series of rigorous aging-focused simulations and reliability cycles. Such processes assess the effects of performance degradation over time and detect potential defects early in the development cycle. Thus, understanding and mitigating semiconductor aging is crucial to this work.

What causes semiconductor aging

Semiconductor aging refers to gradual degradation device performance due to various stress factors encountered during its operational life. By thoroughly examining semiconductor aging, design and development teams can predict how devices will behave over time - ensuring they maintain their routine and reliability standards until the end of their expected life. This comprehensive approach helps deliver robust, high-quality semiconductor products that exceed customer demands and sustain optimal functionality throughout their usage in the field.

There are several possible ways to cause a device to age. Figure 1 shows the significant causes of aging and the reasons often encountered.

It is important to note that the term 'device' encompasses transistors plus various passive and active components. The aging of these individual components collectively contributes to the aging of the entire semiconductor product, as they are the constituent building blocks.

Method	Description
Technology computer-aided design (TCAD)	Provides detailed physical and chemical simulations of device behaviour at the atomic level.
Simulation program with integrated circuit emphasis (SPICE)	Used for circuit-level simulations, incorporating aging models to predict long-term performance degradation.
Define device structure	Set up the physical and electrical parameters of the device.
Incorporate aging models	Use models to simulate mechanisms like HCI, NBTI, etc.

Table 1: Aging focused simulation methods

Validation of semiconductor aging is crucial to ensure that models accurately predict the real-world performance and degradation of devices over time. This process involves simulation methods and reliability studies, primarily focusing on the latter to confirm that the predictions align with empirical data.

1.Simulation methods - Simulation methods predict how semiconductor devices will degrade over time due to various stress factors. Standard models include hot carrier injection (HCI), negative bias temperature instability (NBTI), time-dependent dielectric breakdown (TDDB) and electro migration (EM). Table 1 describes each of these in more detail.

2.Reliability studies - Devices are subjected to real-world stress conditions to validate simulation results and their performance is measured over time. This process ensures that devices meet reliability standards and perform as expected in the longer term. The specific study types are detailed in Table 2.

Key semiconductor aging metrics

Evaluating semiconductor aging involves understanding how devices degrade over time and ensuring they meet reliability standards. 3 of the key metrics used in this evaluation are mean time between failures (MTBF), mean time to failure (MTTF) and failure in time (FIT) rate. Let’s briefly look at how these metrics are useful in semiconductor aging validation:

1.MTBF - This measures the average time between failures during regular operation, thus indicating device reliability. Evaluation includes accelerated life testing, data collection, calculation (operational time/failures) and validation. For example, an MTBF of 20,000 hours means a failure (possibility) every 20,000 hours.
2.MTTF - This measures the average time before a device's first failure, thereby estimating lifespan. Evaluation involves initial testing, data collection, calculation (time to first failure/devices), plus validation. For example, an MTTF of 50,000 hours means a device will operate for that period on average.

Study types	Description
High temperature operating life (HTOL) testing	Devices are operated at elevated temperatures and voltages to predict long-term performance and identify failure modes.
Highly accelerated stress testing (HAST)	Devices are exposed to high humidity and temperature to simulate environmental stress and predict reliability in harsh conditions.
Temperature cycling	Devices undergo repeated heating and cooling cycles to induce thermal stress and assess mechanical durability.
Burn-in testing	Devices are operated continuously at elevated stress levels to identify early failures and ensure long-term reliability.

Table 2: Aging focused reliability study types

3.FIT - This measures the failures witnessed per billion hours of operation, indicating long-term reliability. Evaluation includes accelerated testing, data collection, calculation (failures per billion hours) and validation. For example, a FIT rate 10 means that many failures will occur per billion hours.

Advanced process nodes and the future of aging

Given shrinking process nodes, learning and improving aging analysis is also essential to ensure that semiconductor devices maintain reliability and performance over time. As devices become smaller and more densely packed, they will be more susceptible to various aging mechanisms, as discussed earlier. Advanced (utilising historical process data-based predictive models) aging analysis helps identify these failure mechanisms early - allowing for the development of more robust designs and fabrication processes. By continuously refining aging models and validation methods, as well as incorporating the latest technologies and materials, manufacturers can better predict device behaviour, extend operational lifespans and meet the stringent demands of modern applications.

As semiconductor technology advances, the focus on improving aging analysis will remain pivotal. Emerging techniques, innovative materials and collaborative efforts across the industry will drive the development of more robust and reliable semiconductor products. By prioritising aging analysis, designers and manufacturers can ensure that new products will satisfy modern applications' rigorous demands, sustaining their performance and reliability throughout their operational life.

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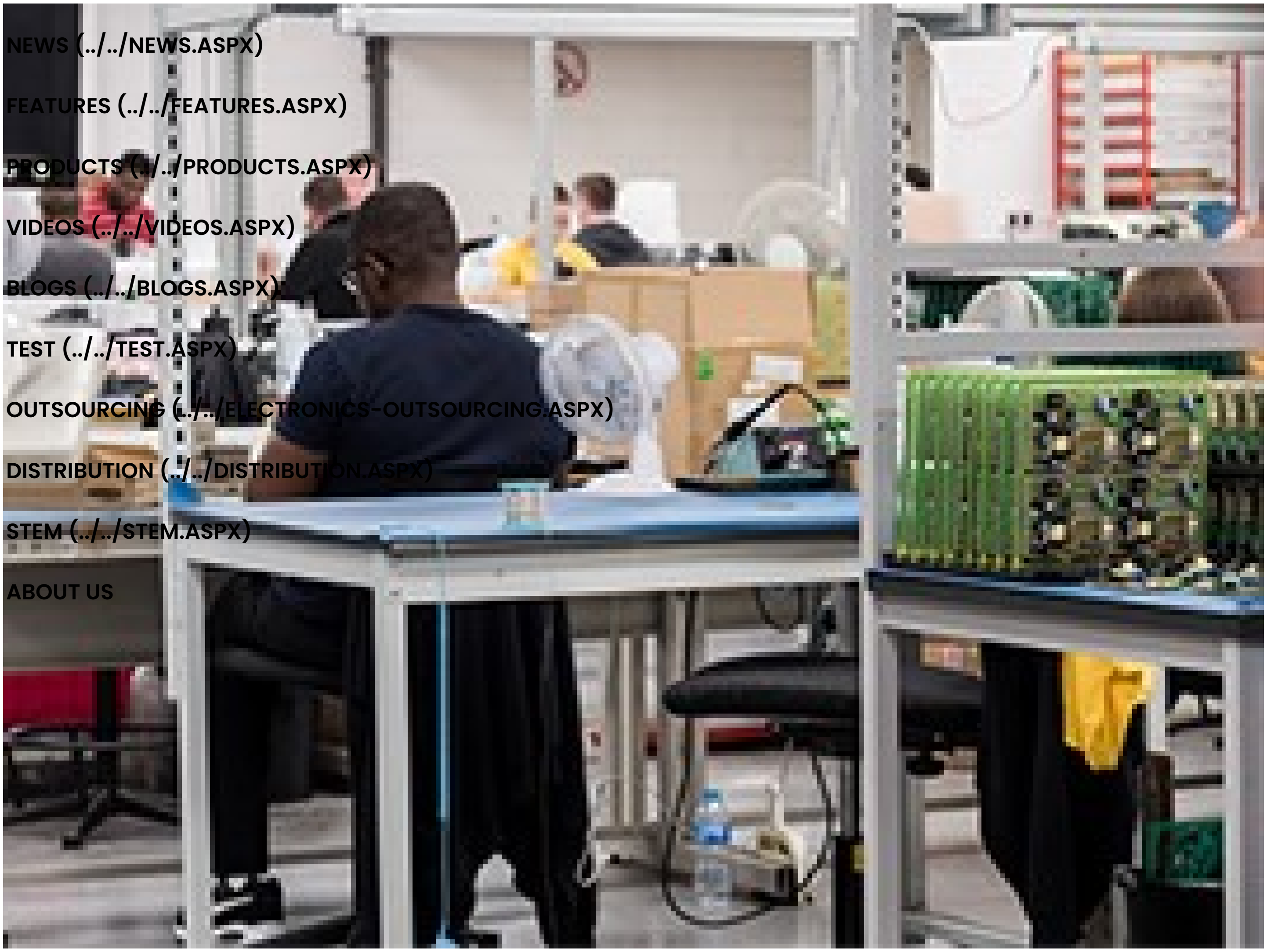

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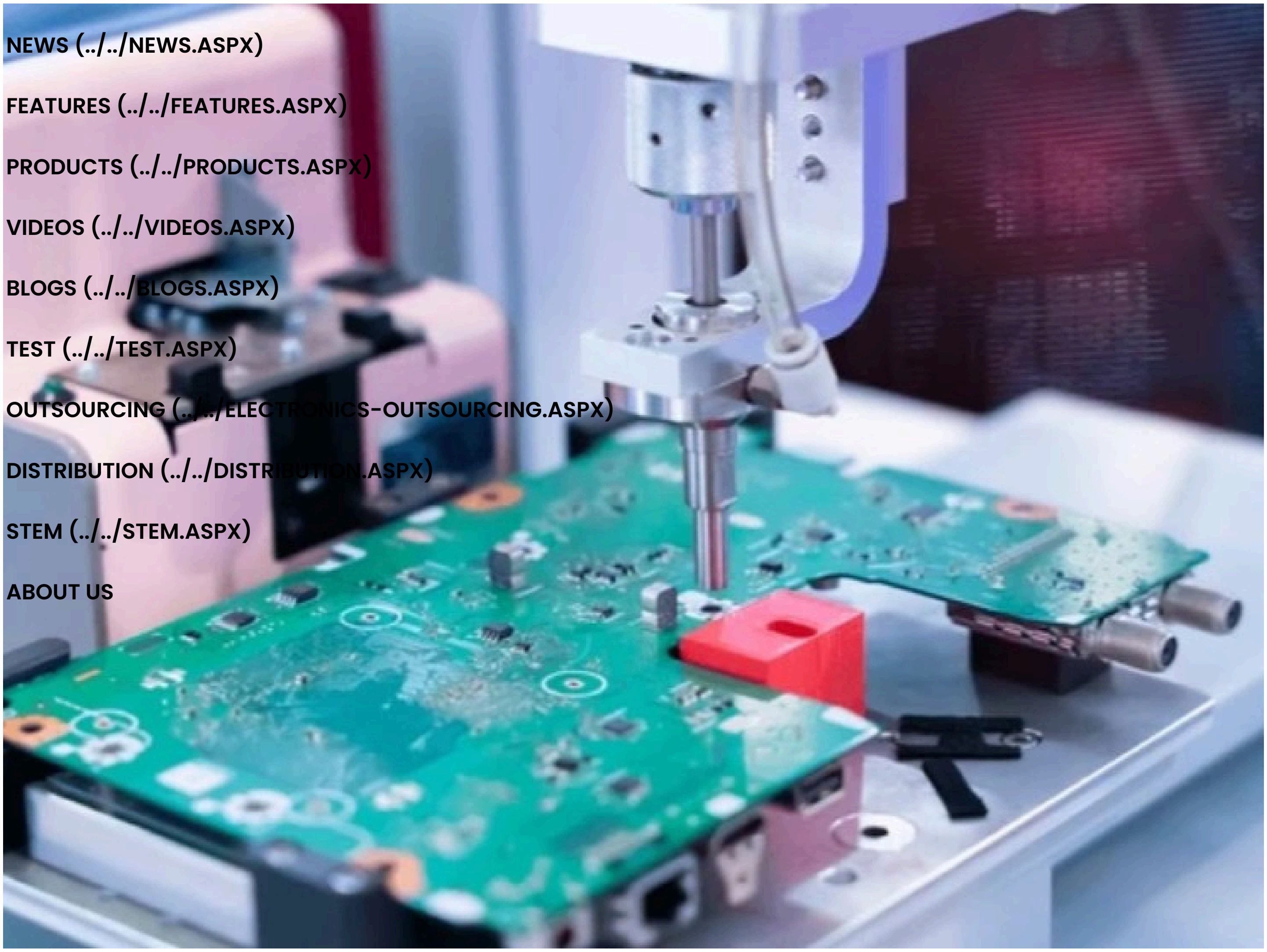

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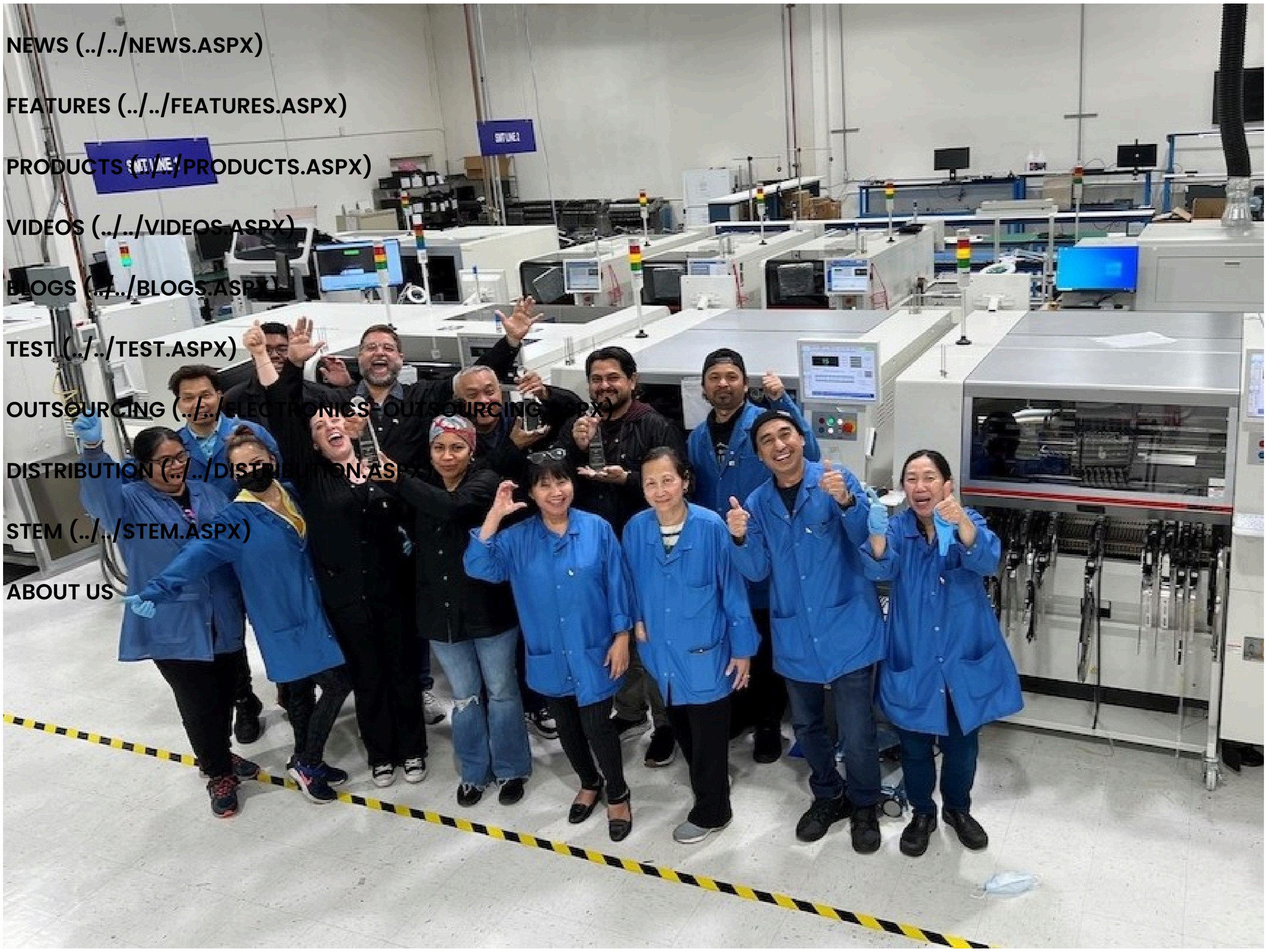

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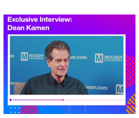

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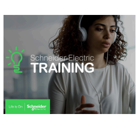

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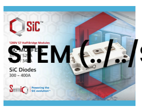

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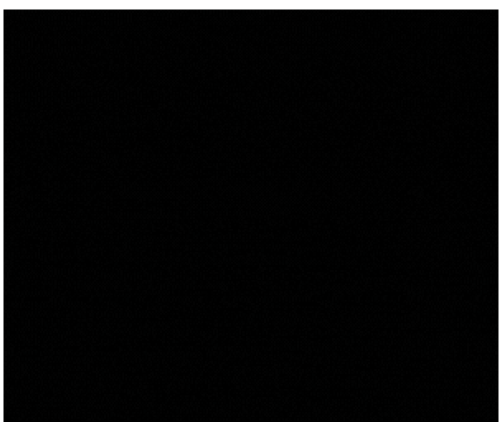

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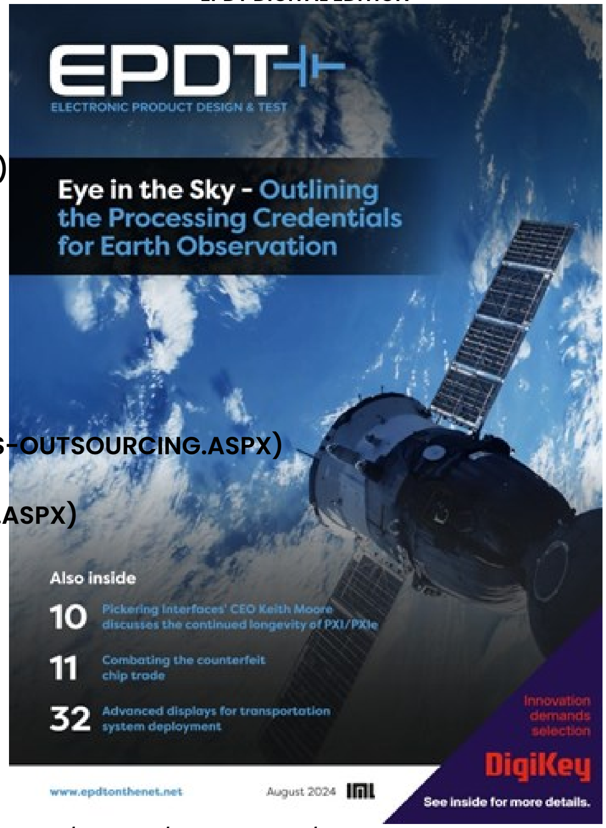

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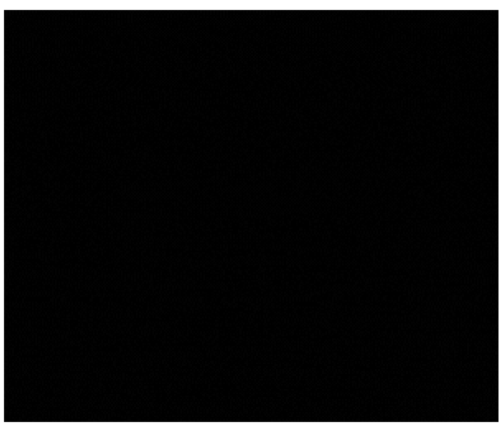
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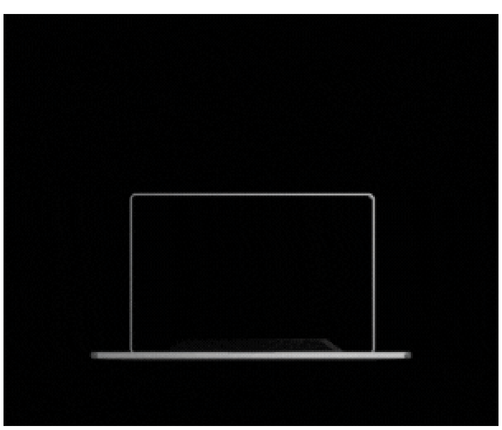
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