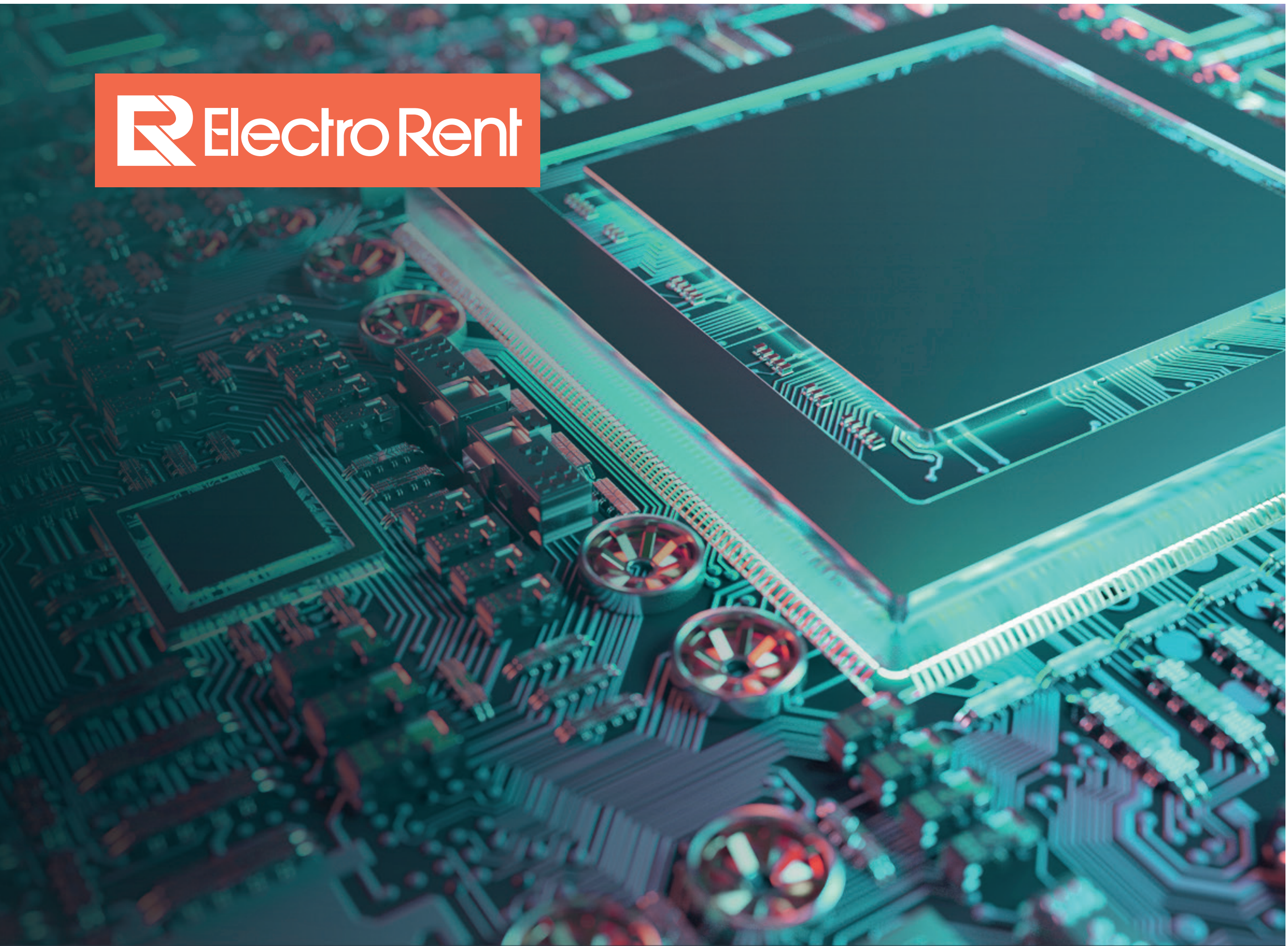


Semiconductor Test

The Technical & Logistical Challenges Now Emerging

electrorent.com

Contents

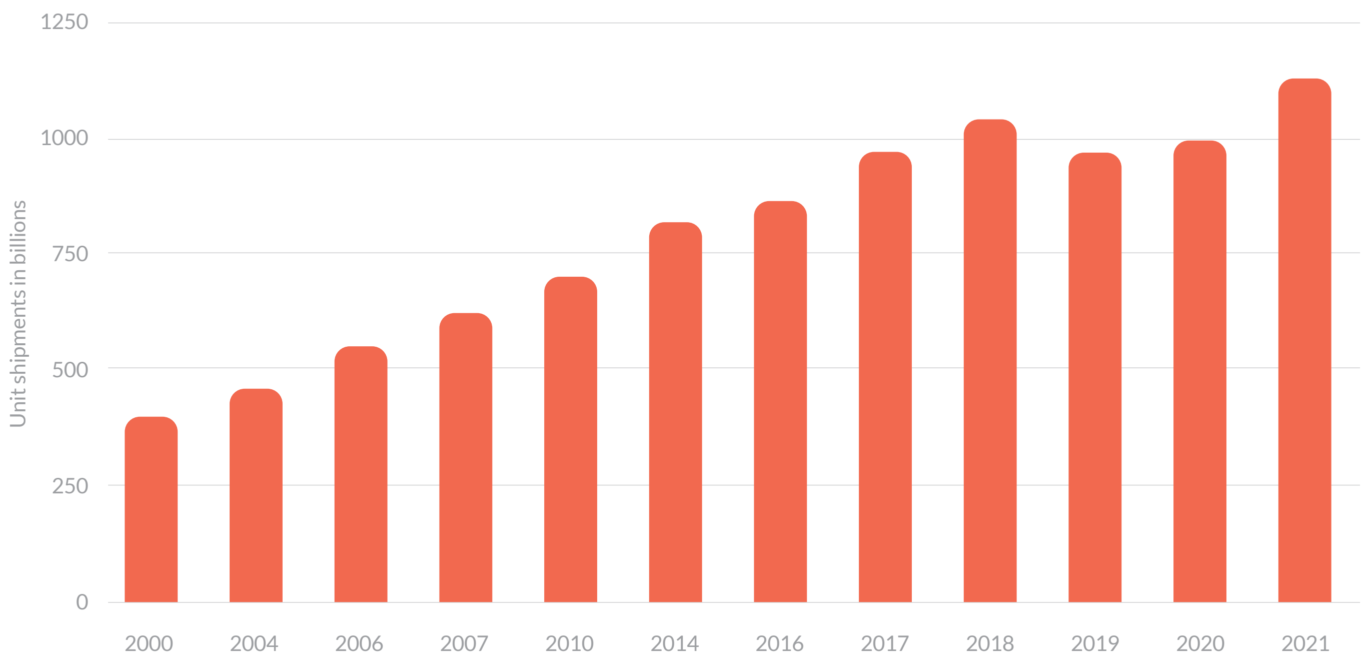
Introduction

The proliferation of semiconductor technology has become so extensive that there is little in our daily life that it does not influence. Present in our cars, portable electronic goods, office equipment, medical instrumentation, industrial machinery, communication infrastructure and countless other places, semiconductor devices are almost ubiquitous.

Despite recent dramatic global events that have challenged every industry, the semiconductor business remains vibrant and continues to gain momentum. Projections made by industry analyst firm Statista expect annual semiconductor shipments to reach an all-time high this year (as noted in Figure 1). This equates to 1.14 trillion units, with a total value of approximately $470 billion. This record growth brings its own set of challenges. Organisations must ramp up production to meet demand while avoiding the overshoot in investment that has followed boom periods in the past. The industry needs to achieve this new investment in the face of cost pressures that are causing companies to look for financial efficiencies.

This whitepaper will explore how the need for continued innovation is changing semiconductor testing and look at how alternative methods of sourcing the essential test equipment can help companies address the challenges they face. These offer a more agile approach that allows them to keep costs under control while maintaining the flexibility to capture market opportunity as it arises.

Figure 1: Global Semiconductor Shipments Since 2000



Source: Statista

Almost two thirds of the annual worth of the semiconductor industry comes from its top ten manufacturers (which are stated in Table 1). In some cases, these are predominantly focused on producing certain types of device, such as memory or communication chips, while others have a broader portfolio comprising a variety of different products.

Integrated device manufacturers (IDMs), such as Intel and Samsung fabricate their own chips. However, many are opting for a fabless business model (like Qualcomm and Broadcom), outsourcing production of their chips to a foundry (e.g. TSMC).

By only paying their foundry partners for the manufacturing capacity they need at any given time, they avoid heavy investment in the equipment needed for production. This frees up financial and human capital to focus on the research and development activities that really drive value. In contrast, IDMs and foundries must continually invest huge amounts of capital to keep up with technological advances and ensure that their fabrication facilities continue to run efficiently. With the costs involved going progressively upward, the number of companies that can continue to fabricate their own devices is contracting.

Though a fabless approach removes the need for production equipment, cleanrooms and suchlike, testing remains an integral activity for fabless companies, IDMs and foundries alike. All can find significant cost efficiencies by sourcing and managing their test inventories more effectively.

Table 1: World's Top Ten Semiconductor Manufacturers 2020

Position	Company	Key Products
1	Intel	Microprocessors
2	Samsung	Memories
3	TSMC	Foundry Services
4	SK Hynix	Memories
5	Micron	Memories
6	Qualcomm	Communication Chips
7	Broadcom	Communication Chips
8	Nvidia	Graphic Processors
9	Texas Instruments	Analogue & Mixed Signal Devices
10	Infineon	Automotive & Power Devices

Source: Statista

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The Rise of the Semiconductor Industry

Following the discovery of the first semiconductor materials in the early 19th century, research over the following century led to the first semiconductor devices, including rectifiers used to detect radio signals. Development accelerated rapidly after the invention of the transistor in the 1940's by William Shockley and his team at Bell Labs, and the industry has kept up a relentless pace ever since.

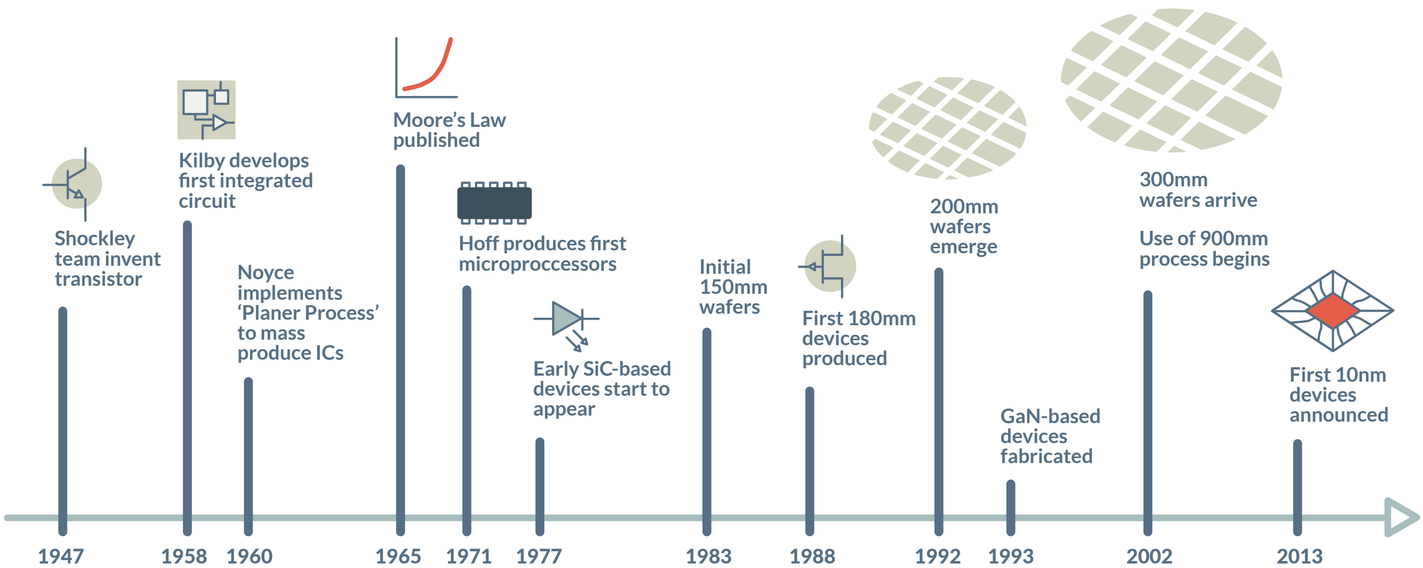
In 1958, Jack Kilby (an employee of Texas Instruments) demonstrated his prototype for an integrated circuit (IC). This would feature a transistor and several passive elements that were all made from the same semiconductor material and had been wire-bonded together. With the birth of the IC, electronic systems to become a lot smaller, cheaper and energy efficient.

Though the IC devices that stemmed from Kilby's prototype enabled miniaturisation of electronic systems, they were difficult to construct. These issues were solved when in 1960, Robert Noyce (of Fairchild Semiconductor) patented the 'Planar Process', through which ICs could be fabricated in large volumes, with the different functional elements (including the interconnects that lay between them) being applied in a succession of deposited layers. Mass production of ICs based on silicon (Si) would be the real turning point for electronics implementation.

Devices became increasingly sophisticated, and snowballing demand led to greater economies of scale. This brought about a reduction in the costs associated with production per unit, which translated into lower price tags for customers.
By extrapolating what had happened over the first few years of IC production, Gordon Moore (who founded Intel with Noyce) made his bold prediction universally known as 'Moore's Law'. Stating that the number of transistors in computer chips would double every two years and, at the same time, the costs involved would halve, it has held ever since.

Moore's law has provided a bar that has driven innovation in the industry over the past five decades pushing organisations to constantly seek new approaches to design and manufacture. This constant iteration and improvement has been accompanied by to regular cycles of 'boom' and 'bust' as demand for new generations of technology at first outstripped supply and then production overshot. The key challenge for the industry is to meet current accelerating demand without overshooting in investment. This needs to be achieved while also investing in the next generation of technologies to continue Moore's legacy for the next five decades and beyond.

Figure 2: Semiconductor Timeline



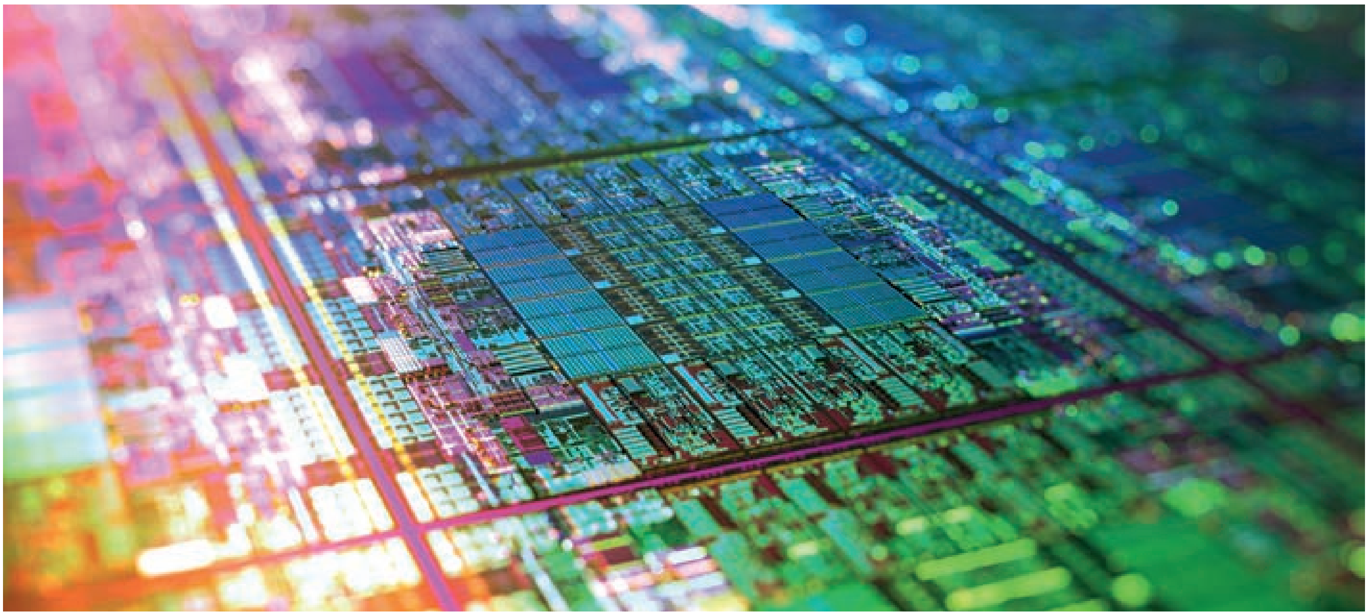
Key Manufacturing Innovations

If the industry was to be able to keep adhering to Moore's Law, then ingenious methods had to be found via which continued increases in transistor numbers could be supported without chips becoming too large and unwieldy for them to be practical to implement. As chips became increasingly intricate, the distance between their features needed to shrink dramatically. Every few years another decrease in the process geometry was announced - taking semiconductor architectures from tens of mms back in the 1970s, through hundreds of nms in the 1980s/1990s, to just a few nms today. The first 2nm semiconductor devices were recently introduced, with ones based on a 1nm process node currently under development (ready for release in the near future).

As well as smaller architectures, there would be a progression in terms of the wafer sizes used too. By moving from 100mm diameters through 125mm and 150mm, to 200mm and most, recently 300mm, it has been possible to boost profitability significantly. Through more rigorous testing, yields have also been improved, making the fabrication process more profitable. The materials that devices would rely on would change too. Though even today Si still constitutes the vast majority of IC production, other semiconductors have shown themselves to be very well suited to particular applications. For example, silicon-germanium (SiGe) has been pivotal in high-speed communication. Likewise, wide-bandgap technologies, such as silicon-carbide (SiC) and gallium-nitride (GaN), have resulted in substantial enhancements to modern power systems. Power devices that are based on either GaN or SiC technology are able to outperform their conventional Si-based counterparts, with the capacity to withstand higher voltages and working temperatures. They can support accelerated switching speeds and exhibit significantly lower thermal losses.

The combining of multiple heterogeneous dies together is something that many chip manufacturers are now starting to see a lot of potential in too. It means that the inherent advantages of different semiconductor technologies can be benefited from. The complexity of these system-in-package (SiP) solutions does pose significant difficulties from a test perspective though.

It is likewise becoming increasingly commonplace for memory chips to feature multiple dies that have been tightly stacked together in order to ramp-up the overall data storage capacity - presenting a route to go beyond the confines of Moore's Law. With the performance of chips being boosted and the number of dies within devices increasing, improvements needed to be made to the packaging (so that heat can be better dispersed).



Changes to How Semiconductor Test is Conducted

Progress in IC design and manufacture has been dramatic since their initial conception 60 years ago. Today the state-of-the-art graphic processor unit (GPU) chips can contain over 50 billion transistor gates. There was just one in Kilby's original IC prototype.

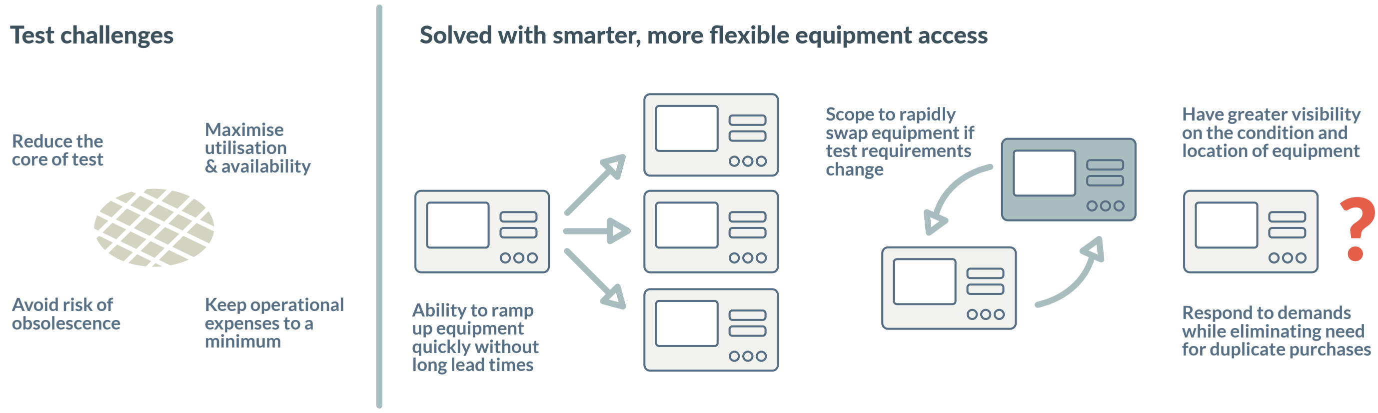
Though the first IC appeared over 60 years ago, the objectives for chip manufacturers have changed very little since then. By leveraging the latest technological advances, they must keep on producing devices that continue to push the performance envelope. With each new generation, devices need to offer greater degrees of functionality, take up less area on a PCB and require a lower power budget.

It is estimated that the semiconductor sector's total annual research and development (R&D) spend for 2021 will exceed $71 billion (according to IC Insights), which is a 4% increase on the previous year. Intel and Samsung are unsurprisingly the biggest spenders here (their combined outlay coming close to $20 billion), with Nvidia, Mediatek and AMD also included within the top ten. There is no sign that things are slowing down either - the overall figure is set to keep rising, with investments forecast to push past the $89 billion mark by 2025.

The test equipment installed on production lines and found in development labs will represent a large proportion of the aforementioned R&D investment - so semiconductor manufacturers need to use the budget available for this wisely, if they are going to get the most out of it. This is unfortunately not always what happens though.

Data compiled by market analysis consultancy Frost and Sullivan suggests that technology companies' test equipment may only end up being employed approximately 20% of the time. Low utilisation rates like these indicate that their inventory management and equipment sourcing is not optimal. Therefore, a growing number of organisations are seeking to gain greater value from their test and measurement inventories and operations.

Figure 3: Test Engineers' Equipment Priorities



Understanding a Mixed Approach to Equipment Sourcing

Though most semiconductor manufacturers still purchase much of their test equipment, this is mainly due to habit rather than through a careful evaluation of the options available. With R&D and quality assurance managers being increasingly concerned about the cost of test spiraling, and uncertainty about what technologies will be adopted in the future, there is a strong need for companies in this sector to think again about their sourcing methods.

The following scenarios highlight some of the current market challenges, and how a fully considered procurement solution can help to overcome them.

1. Meeting Sudden Increases in Demand
If a production facility needs to ramp up its output suddenly due to OEM demands, extra equipment is needed. But that demand might not be sustained, so this can result in kit becoming redundant. Having seen regular boom and bust cycles play out over the years, manufacturers must be fully prepared to scale up production as their products get commercial traction, while also protecting themselves against the dangers of overinvesting. More flexible equipment acquisition solutions such as rental can help mitigate the risk of overshooting.

2. Managing Restricted Budgets
The growing number of fabless start-ups need to be able to test and characterise their devices just like their larger counterparts. But with limited capital available to them, they are under even greater financial constraints. This makes the need for a test equipment strategy that avoids heavy up-front investment more than just preferable - it is an outright necessity. The same will be true for IC design houses, due to the relatively small size and the variability of their work (as they will be moving from one project to another, with each having its own distinct test requirements). Equipment rental is another attractive option in these cases, as well as financial solutions that spread the costs to work with funding cycles.

3. Accounting for Unexpected Test Requirements
Project budgets are often fixed up-front, however changes can occur over the course of the project requiring additional test equipment. Additional budget for such equipment can be difficult to obtain once the project is underway. This can result in engineering compromises being made - which will stifle innovation. Short-term access to equipment from a specialist supplier enables sourcing of the latest testing technology needed to complete the project funded from the operation budget. This avoids lengthy CapEx approvals which can hold projects up, and the burden of purchasing equipment that might not be needed further down the line.

4. Adapting to the Pace of Technology Change
New standards are emerging all the time, especially in relation to the embedded interface and wireless communication standards that need to be supported. There is the potential for equipment that has been purchased to quickly become outdated. By identifying alternative sourcing options for equipment that is at most risk of early obsolescence, the chance of being left with outdated equipment can be greatly reduced. Rent-to-buy arrangements that offer an option to purchase at the end of the agreement or return the instrument at the end of a fixed period can help semiconductor manufacturers to future proof their test activities while reducing the risk of costs spiraling out of control.

Subjected to severe cost and logistical pressures, companies involved in the semiconductor industry must formulate test equipment sourcing strategies that are better aligned with their actual needs. Rather than sticking to the traditional approach of purchasing new equipment as situations dictate, they need to display more agility. This will enable them to address the requirements of a particular project, or attend to potential test capacity fluctuations, without the risk of being stuck with redundant items that become a financial burden

The working lifespan of test equipment being used within a semiconductor context is relatively short, and the rapid pace at which new standards emerge will mean that it is only likely to become further shortened in the years ahead. Semiconductor manufacturers must respond to this, finding more flexible and cost-effective ways via which they can source equipment.

It should also be noted that current chip shortages are impinging on OEM engineers' ability to develop advanced systems solutions. To prevent production hold-ups that could mean that windows of opportunity are missed, designs often need to be reworked at short notice. Companies must therefore have much greater flexibility when it comes to their testing processes, with the flexibility to swap equipment for instruments that are more relevant to the new design.

A more adaptable test sourcing strategy, utilising the right combination of sourcing methods, including equipment rental, used equipment purchase and financial solutions that spread the cost and risk of purchase, will allow R&D activities to be better matched to any changes in market conditions. This will mean that companies have the flexibility needed to capitalise on prospective opportunities, but without making themselves financially vulnerable through overinvestment.

Unlocking Inventory Value with Asset Optimisation

In addition to altering their approach to equipment sourcing, organisations can achieve efficiencies by better understanding the test inventory they hold and how they use it. Armed with data on the equipment's make, model, and key specifications, as well as its current location, when it was last serviced, its calibration status, etc. they can make more informed decisions. Utilisation levels can also be investigated enabling procurement managers to more easily decide whether extra units are needed. Unused equipment can also be sold to free up cash for investment elsewhere.

Many clients have been able to double their equipment utilisation levels using these asset optimsation tools. In some cases, they have been able to reduce their unplanned equipment purchases by as much as 70%, and their staff spend far less time having to concern themselves with managing their test assets or searching for items for which there is an immediate requirement. They can also use this improved knowledge of their equipment inventory to make better sourcing decisions.

Equipment Available - Device Characterisation

The migration to smaller architectures, as adherence to Moore's Law entails, enables reductions in device sizes, increases in the feature sets that they can support, curbs their power consumption and allows a lowering of their unit costs. However, there are much higher degrees of intricacy involved and these cannot be overlooked.

Greater use of new materials (such as GaN and SiC), three-dimensional (3D) stacking of dies, multi-die SiP solutions and next generation packaging formats all add to the problems that test engineers are being set. More detailed device characterisation is thus required, so that it can be accurately ascertained that devices being produced possess the necessary performance parameters.

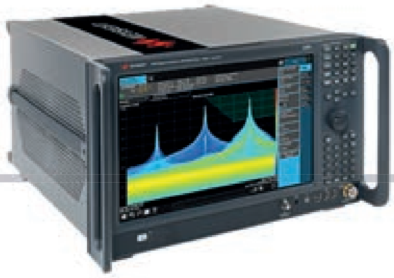
The **Keysight Technologies Infiniium UXR** incorporates the most powerful and technologically advanced analog front end of any real-time oscilloscope. Available with bandwidth of 5 to 110 GHz, it offers a comprehensive set of probing, analysis applications, and measurements for advanced technologies. With its leading-edge Indium Phosphide chip technology, custom thin film multi-chip module packaging and integrated Faraday cage architecture it guarantees the speed, low noise, and high fidelity needed to capture and measure both current and future high-bandwidth low-voltage signals.

Intended for the characterisation of the latest RF transceivers, the **R&S®ZVA network analyzer from Rohde & Schwarz** is an invaluable tool for semiconductor test engineers. It has an expansive frequency range that spans from 10MHz to 110GHz, with a 1Hz frequency resolution. The measurement time per test point below 3.5µs in the CW, with a frequency sweep over 200 test points being completed in just 5ms. The 140dB dynamic range allows identification of the causes of signal loss.

Equipment Available - Conformance Testing

There are a diverse range of communications standards that electronic hardware must now support. 5G's arrival has mandated the opening up of new frequency bands (in both the mmWave and sub-6GHz spectrums). The need for greater wireless bandwidth in homes, offices and public spaces means that older WLAN technologies are now being superseded by 802.11ax. The advent of the Internet of Things (IoT) is encouraging widespread uptake of cellular protocols (like NB-IoT and Cat-M), as well as other LPWAN protocols (such as Sigfox and LoRa). The high-speed interfaces now being incorporated into embedded systems are based on the latest versions of PCIe, while industrial, enterprise and automotive networking hardware are all using multi-Gigabit Ethernet standards. To ensure that ICs provide the signal integrity needed to support these different cellular, wireless and wireline protocols, comprehensive conformance testing is called for.

Optimised for high-throughput conformance test work, **Rohde & Schwarz offers the R&S®CMW500 wideband RF test unit.** It can be used to look at the operational parameters of cellular, WLAN and Bluetooth chips to ensure compliance with the necessary protocols. It may also be employed in order to validate the C-V2X communication ICs being integrated into modern vehicle designs.



The **Keysight UXA signal analyzer** enables engineers to characterize today's most challenging signals — fast-hopping, wideband, transient — in 5G, 802.11ax/ay, satellite, radar, electronic warfare etc. With industry-leading phase noise and wide spurious-free dynamic range, it gives wider (up to 1 GHz), deeper views of the most challenging signals. Capture intermittent signals with gap-free, real-time spectrum analysis and lower-level spurious signals with an improved DANL low noise path.

Conclusion

As we move into the 7th decade of IC production, their prevalence is greater than ever. The number of items of handheld equipment that each person owns continues to increase. The quantity of ICs being incorporated into cars is still rising too, and as higher degrees of autonomy are implemented in the years ahead, this will reach unprecedented quantities. The mass roll-out of IoT infrastructure means that billions of sensor nodes are now starting to be put into operation. The growing popularity of cloud-based services will call for a sharp ramp-up in data storage capacity, thereby fueling ever-greater demand for memory chips. Artificial intelligence (AI) based systems are simultaneously driving development of more complex microprocessors and graphic processing units (GPUs). Wearable, hearable and implantable technology means that numerous ICs are now being placed on or even inside our bodies.

These technological wonders are only possible through constant research and development, and the careful evaluation of the functionality and performance of their constituent semiconductor devices. Accurate testing is paramount and the investment that semiconductor manufacturers make in testing their products constitutes a sizeable element of their annual capital and operational costs. Therefore, testing must be done in a cost-effective manner, keeping equipment utilisation as high as possible, and unplanned purchases and inventory to a minimum.

By following a multifaceted test equipment sourcing strategy that is based on a careful mix of rental, purchase (both new and used) and financial solutions which spread costs efficiently, semiconductor companies can adapt to any eventuality. The latest equipment can easily be accessed, then swapped for other items as the relevant testing criteria change. It eliminates the risk of being stuck with expensive instruments that are no longer needed, avoiding unnecessary ongoing operational costs (insurance, finance repayments, maintenance, etc.).

This flexible mixed approach to equipment sourcing is equally useful to small start-up fabless companies, semiconductor research institutes and design houses, as it is to large-scale IDMs. It offers highly agile access to the latest testing technology, including oscilloscopes and parametric analyzers required for characterisation work, as well as the spectrum analyzers and RF testers needed to conduct physical layer and conformance testing.

With a global equipment inventory valued at over $1bn, Electro Rent offers customers access to thousands of instruments available directly from stock. Equipment can be sourced via a variety of different methods. These include short-term rental, hire purchase, operational leasing and rent-to-buy options, as well as certified pre-owned equipment. Immediate availability means that these items can be implemented into existing workflows within short timeframes, so production demands are not held up. The Electro Rent team is always on hand to help customers find the right equipment for their technical requirements, matched with the most appropriate sourcing solution.

Taking this more considered approach to equipment procurement, along with optimising the use of existing test assets, results in significant increases in utilisation - with improvements of over 40% being commonplace. Financial reserves no longer need to be tied up in unused hardware. Test expenditure can be optimised and reduced, while profits will rise as new designs reach the market sooner. Furthermore, through asset optimisation, they will be able to make their operations more efficient, with elevated levels of productivity being attained and wastage eliminated. Working capital that would have previously been unavailable can then be channeled into other areas of the business.

By ensuring they have the equipment they need exactly when they need it, engineers can concentrate on what they do best – innovating to create the new semiconductor devices that will drive the next 50 years of growth.

Electro Rent

Smarter Solutions for Testing & Technology

About Us

Electro Rent is a leading global provider of test and technology solutions that enable customers to accelerate innovation and optimize asset investments. Our rental, leasing, sales, and asset optimization solutions serve innovators in communications, aerospace and defense, automotive, energy, education, and electronics industries, and we have been doing so since 1965.

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