September 25, 2024

Semiconductor Market and Test Technology

2024 SEMI Korea Test Tutorial

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ATE Applications, South Asia & Korea VP

Agenda

- Semiconductor Market
- History of Electronics and Semiconductor Technology
- Structure of Automatic Test Equipment (ATE)
- Advanced ATE Technology
- Q&A

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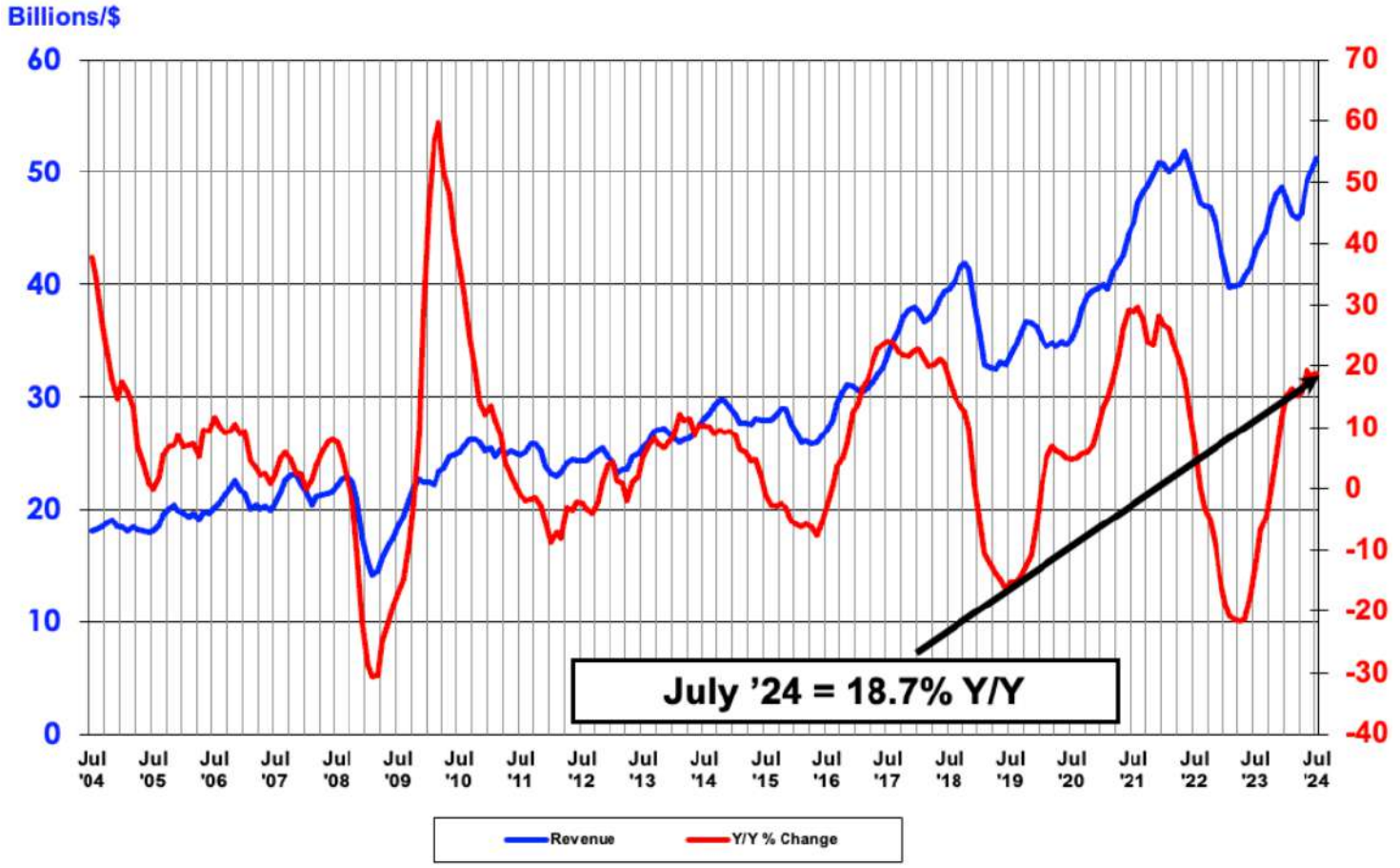
Semiconductor Market

Semiconductor Market Revenue

Global Semiconductor Sales Increase 18.7% Year-to-Year in July

- The Semiconductor Industry Association (SIA) today announced global semiconductor industry sales hit $51.3 billion during the month of July 2024, an increase of 18.7% compared to the July 2023 total of $43.2 billion



1) *Source:* Press Release: 09/03/24 by Semiconductor Industry Association

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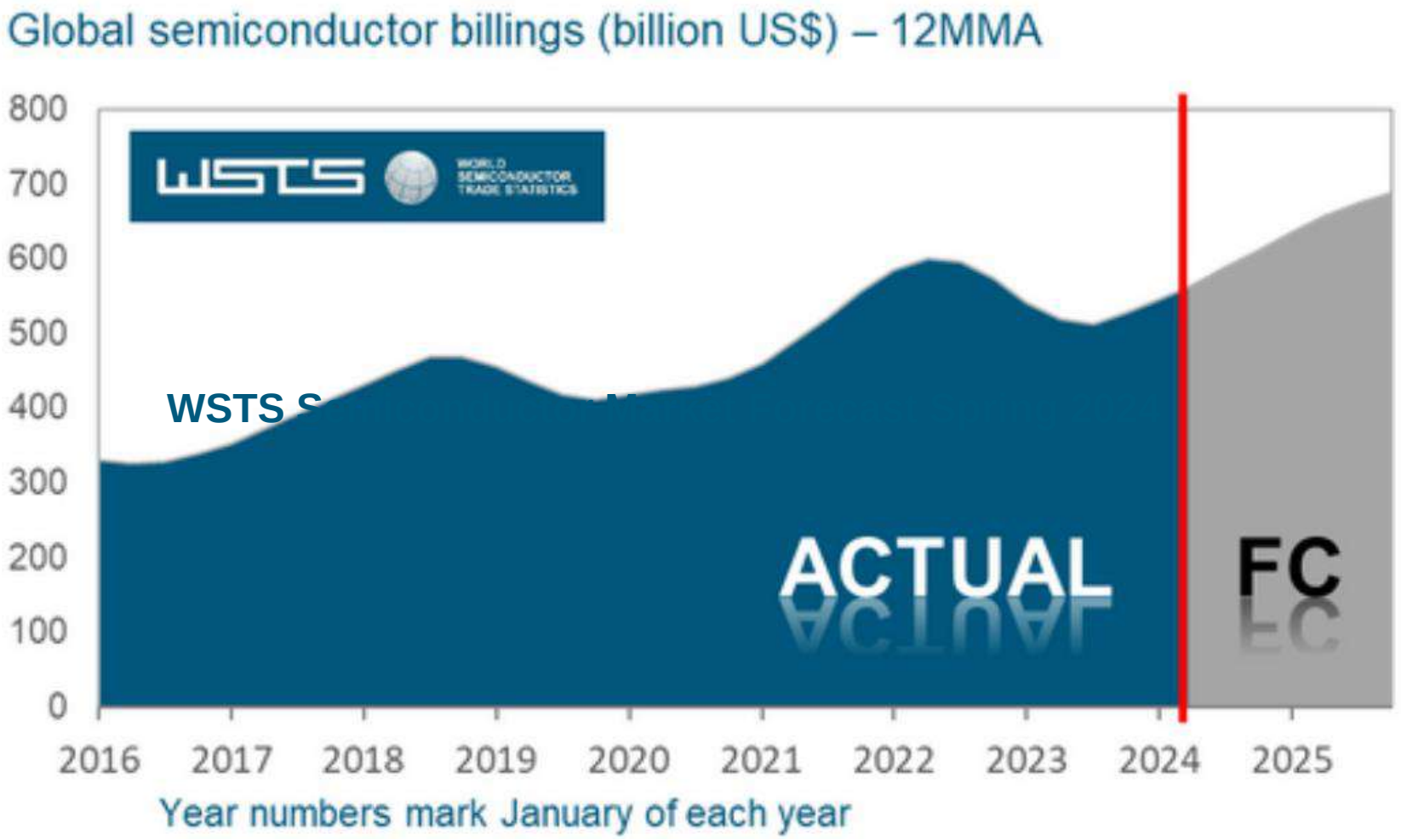
WSTS Semiconductor Market Forecast Spring 2024



Source: WSTS 2024 spring forcast

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WSTS Semiconductor Market Forecast Spring 2024

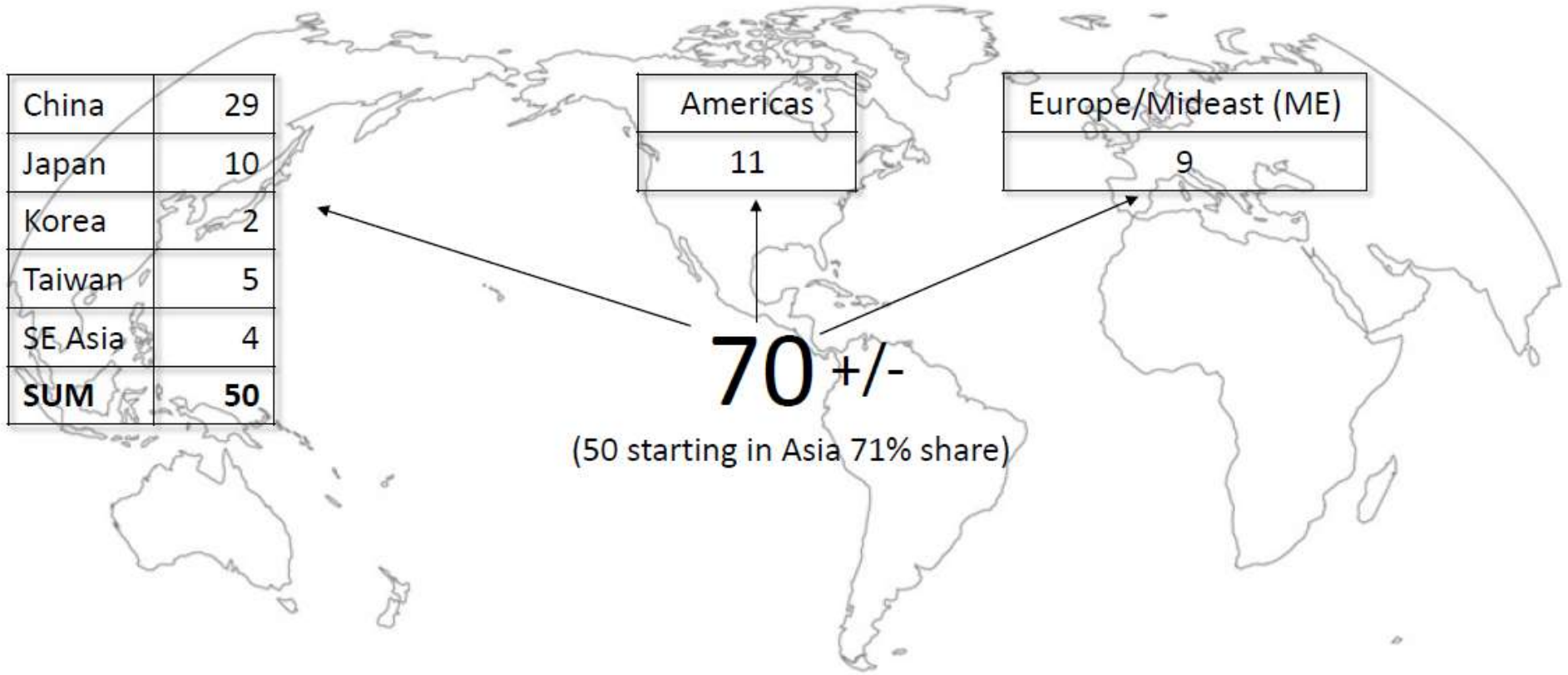
Summary

Spring 2024	Amounts in US$M			Year on Year Growth in %		
	2023	2024	2025	2023	2024	2025
Americas	134,377	**168,062**	**192,941**	-4.8	25.1	14.8
Europe	55,763	**56,038**	**60,901**	3.5	0.5	8.7
Japan	46,751	**46,254**	**50,578**	-2.9	-1.1	9.3
Asia Pacific	289,994	**340,877**	**382,961**	-12.4	17.5	12.3
Total World - $M	526,885	**611,231**	**687,380**	-8.2	16.0	12.5
Discrete Semiconductors	35,530	**32,773**	**35,310**	4.5	-7.8	7.7
Optoelectronics	43,184	**42,736**	**44,232**	-1.6	-1.0	3.5
Sensors	19,730	**18,265**	**19,414**	-9.4	-7.4	6.3
Integrated Circuits	428,442	**517,457**	**588,425**	-9.7	20.8	13.7
Analog	81,225	79,058	84,344	-8.7	-2.7	6.7
Micro	76,340	77,590	81,611	-3.5	1.6	5.2
Logic	178,589	197,656	218,189	1.1	10.7	10.4
Memory	92,288	163,153	204,281	-28.9	76.8	25.2
Total Products - $M	526,885	**611,231**	**687,380**	-8.2	16.0	12.5

Source: WSTS 2024 spring forcast

Volume Fabs Starting Construction from 2023 to 2025

2023: 33 → 2024: 26 → 2025: 11



Data includes EPI.

Source: C.G. Dieseldorff, Market Intelligence Team (MIT), July 8, 2024.

Volume Fabs Starting Construction: '20 to '22 vs '23 to '25

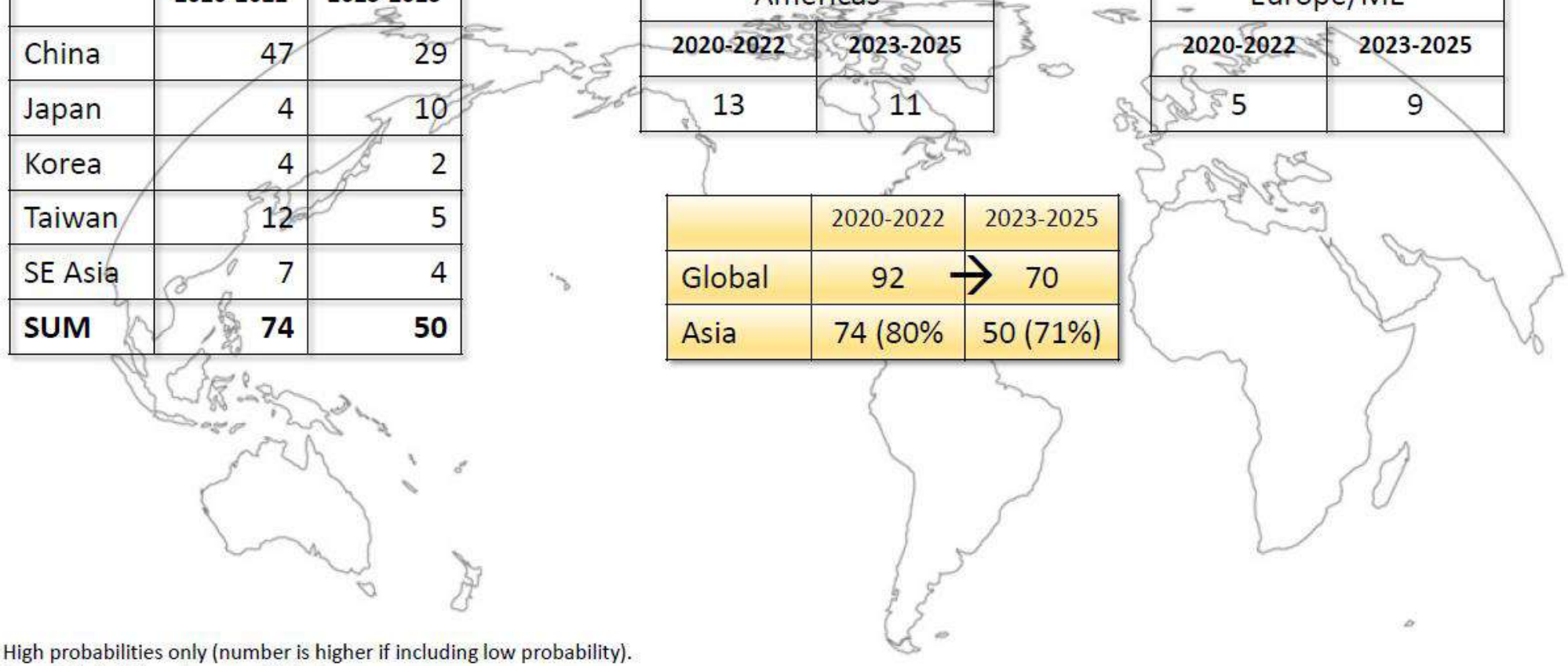
Some slow down seen in 2023-2025

	2020-2022	2023-2025
China	47	29
Japan	4	10
Korea	4	2
Taiwan	12	5
SE Asia	7	4
SUM	**74**	**50**

Americas	
2020-2022	2023-2025
13	11

Europe/ME	
2020-2022	2023-2025
5	9

	2020-2022	2023-2025
Global	92 →	70
Asia	74 (80%	50 (71%)

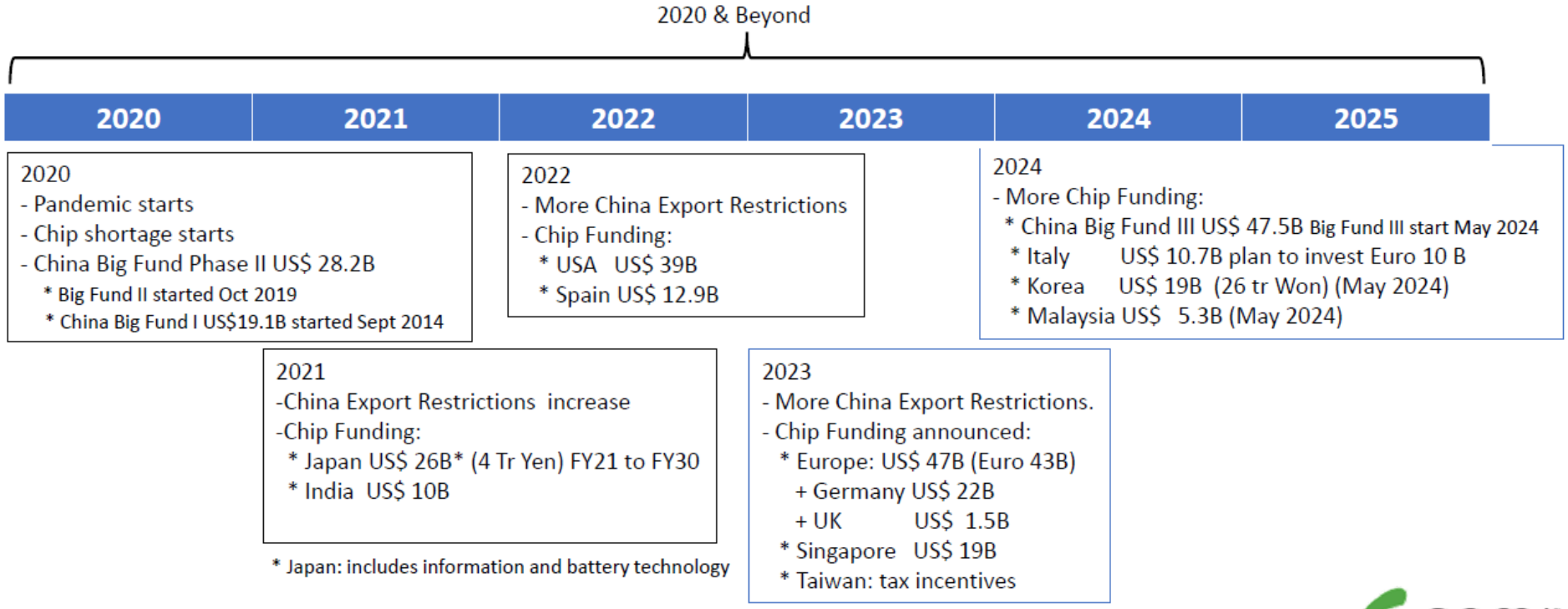


High probabilities only (number is higher if including low probability).
Some Fab buildings have multiple cleanrooms.
This counts construction start of individual Front End Fab buildings only (including EPI.) We adjust Fab count to company reports.

Source: C.G. Dieseldorff, Market Intelligence Team (MIT), July 8, 2024.

The 2020 & Beyond Era and Government Interventions

- Pandemic triggered high demand for semiconductors
- Combined with supply chain issues, this caused a severe chip shortage
- Geopolitical tension, such as China export restrictions, and increased government funding caused a regional shift in activities



Source: C.G. Dieseldorff, Market Intelligence Team (MIT), July 8, 2024.

Milestones and Timing of New Fab Projects

- Fabs starting construction in 2023 will start equipping in 2024 (earliest) – if no other hurdles

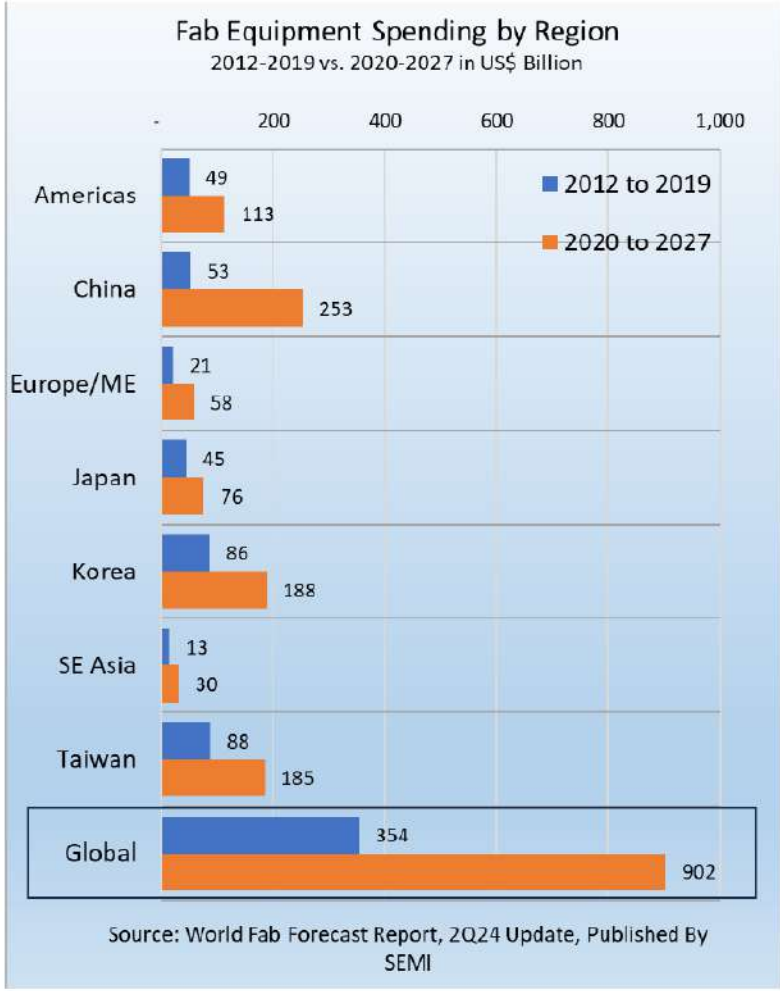
Timing depends on many factors

1. Size of Fab (25K wpm vs 150K wpm)
2. Wafer size (12", 8", <8")
3. Product Type (leading edge logic, memory, power, etc)
4. Location
5. Company's strategy and budget
6. Market condition
7. Supply chain
8. Availability of Labor/Talent

Source: C.G. Dieseldorff, Market Intelligence Team (MIT), July 8, 2024.

Total Fab Equip. Spending: Comparing Different Periods

Pre-Pandemic (2012-2019) vs. 2020 & Beyond (2020-2027)



- From 2020 to 2027, US$ 902B will be invested into Fab equipment globally, boosting by US$ 548B or 155% compared to 2012 to 2019.
- China is adding most in 2020 to 2027 with 382% or US$ 200B.
- Europe/ME and Americas are in 2nd and 3rd place, respectively percentage-wise but not in actual dollar values.

	Change 2012-2019 to 2020-2027		2020 to 2027
	Change %	Increase in US$B	Total Invest $B 2020 to 2027
China	382%	200,726	253,239
Europe/ME	181%	37,233	57,778
Americas	129%	63,563	112,962
SE Asia	123%	16,559	30,039
Korea	119%	101,974	187,749
Taiwan	111%	97,199	184,720
Japan	68%	30,648	75,789
Total	**155%**	**547,903**	**902,2**

Source: World Fab Forecast Report, 2Q24 Update, Published by SEMI

Largest increase in %

Largest total spending

Source: C.G. Dieseldorff, Market Intelligence Team (MIT), July 8, 2024.

Toal Fab Equip. Spending: Spending by Product Type

2020 & Beyond: Comparing 2020-2023 to 2024-2027

In 2024 to 2027, US$ 538B will be invested into Fab equipment globally, boosting by US$ 174B or 48% compared to 2020 to 2023.
Three regions re-emerge, one emerges, but China, Korea and Taiwan still rule

	Change 2020-2023 to 2024-2027		2024 to 2027	
	Change %	Increase in US$B	Total Invest $B 2024 to 2027	
Europe/ME	123%	22,019	38,899	Re-emerging Regions
Americas	119%	42,114	77,538	
SE Asia	91%	9,391	19,715	Emerging Region
Japan	48%	14,580	45,185	Re-emerging Region
Korea	36%	28,341	108,045	
China	33%	35,588	144,414	Largest
Taiwan	27%	21,813	103,267	
Total	**48%**	**173,846**	**538,061**	

Source: World Fab Forecast Report, 2Q24 Update, Published by SEMI

Source: C.G. Dieseldorff, Market Intelligence Team (MIT), July 8, 2024.

History of Electronics and Semiconductor Test Technology

History of Semiconductor Technology

1904 — **Vacuum Tube**
By Fleming and Amplifier

1918 — **Radio & Telecommunication Technology**
AM Modulation and IF
Super-heterodyne Technology

1928 — **Video Signal Processing Technology**
Black and White Color Signal Processing
Color Video Processing I/Q Modulation
& PLL Technology

1947 — **Transistor**
By Bell Labs

1958 — **IC Technology**
By Fairchild & T.I., Jack Kirby

1961 — **MOS Transistor**
Patented by Dawon Kahng

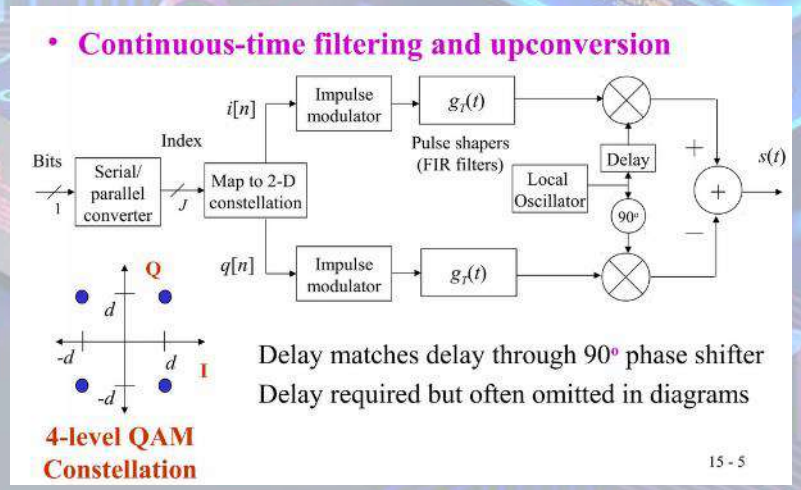
1966 — **DRAM Prototype**
By IBM

1969 — **CCD**
By Bell Labs

1980 — **PC**
By IBM

1992 — **Mobile Phone 1992 and after**
CDMA/GSM/LTE/WCDMA
2G, 3G, 4G, 5G mmW & 6G
expanding wireless network

2003… — **Smartphones, AP Processor, & Big Data Communications Technology**
Digital video processing
Computing & Data storage – GPU & cloud
Automotive SiC/GaN, ADAS for xEV
High-density & high-speed data transmission TSV (HBM) to AI & edge processing
Opto. I/F for extra high-speed data comm.



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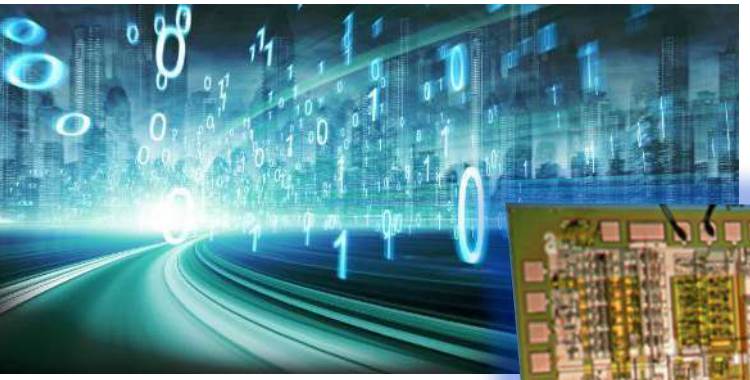
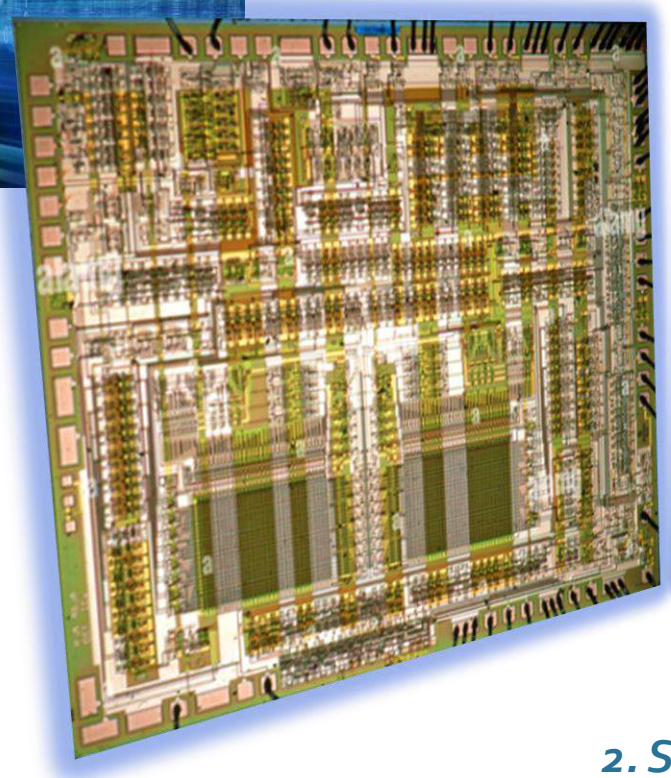
Overview – Semiconductor IC, Test, and Interface

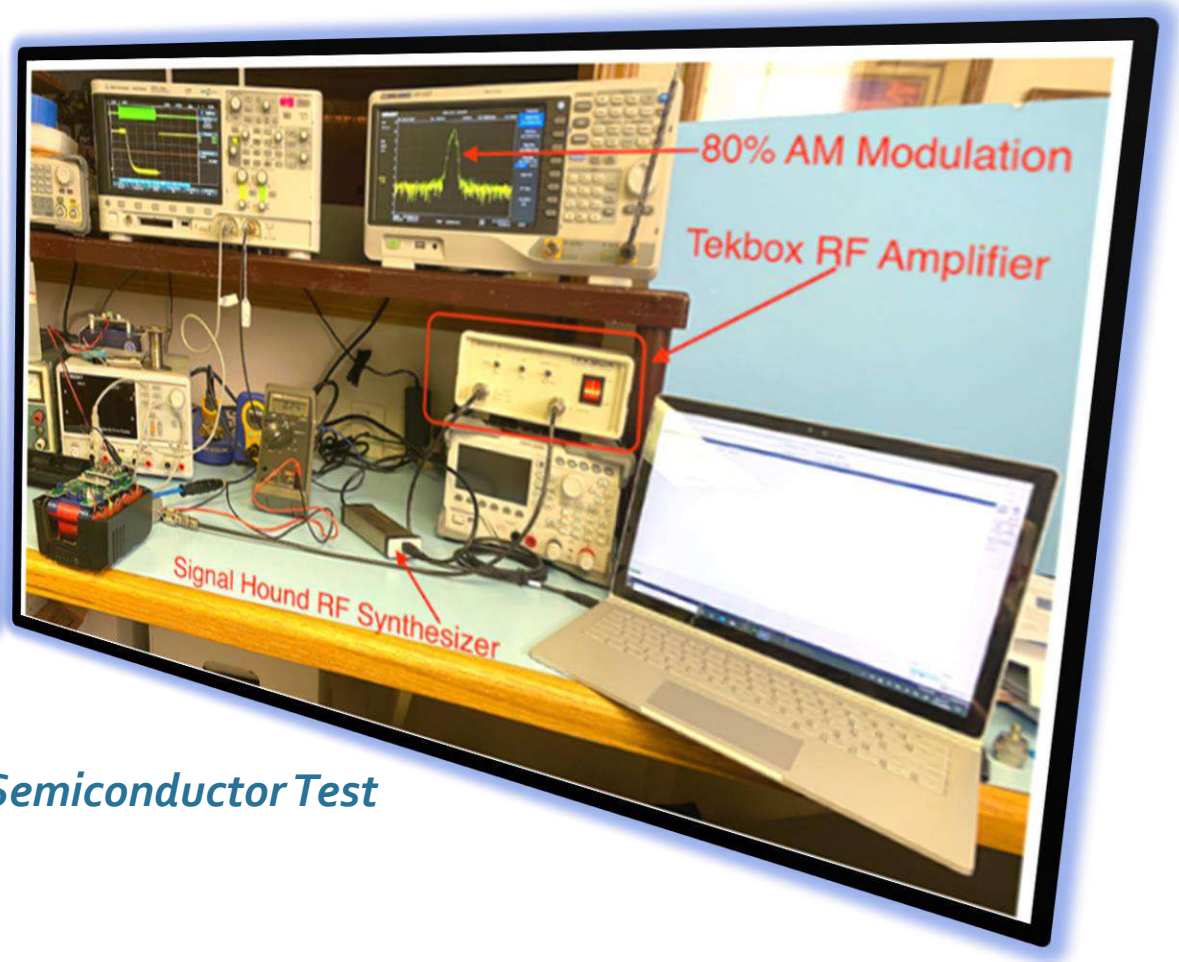


What do I need to know to test integrated circuits?

1. Semiconductor Design

Spec generation
&
Test requirement





2. Semiconductor Test

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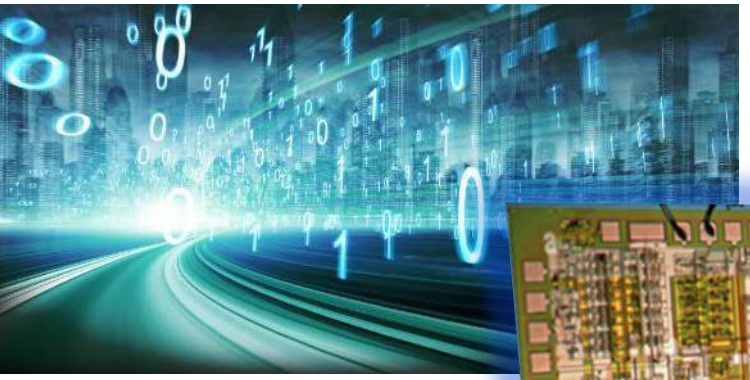
Test, and Interface



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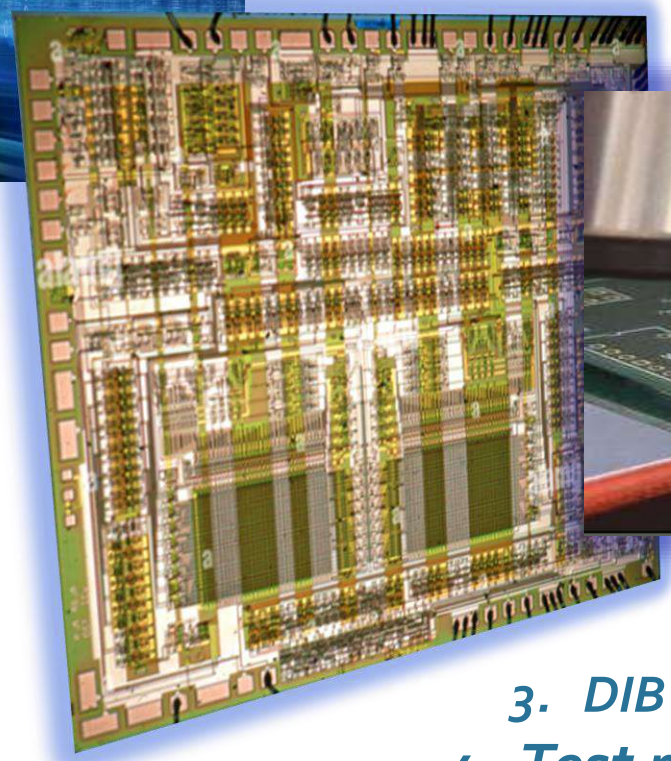

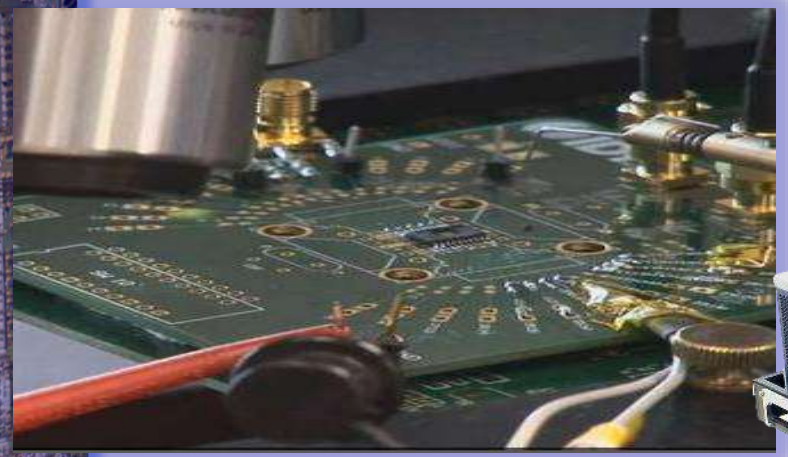

1. Semiconductor Design

Spec generation & Test requirement

2. Semiconductor Test

3. DIB and PIB Interfacing IC and ATE

4. Test programming and Debugging

5. Correlation and production testing

Tester (ATE)

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General IC Tests

Test	Stage of IC Manufacture	Wafer-or Chip-Level	Test Description
IC Design Verification	Pre-Production	Wafer level	Characterize, debug and verify new chip design to insure it meets specifications.
In-Line Parametric Test	Wafer fabrication	Wafer level	Production process verification test performed early in the fabrication cycle (near front-end of line) to monitor process.
Wafer Sort (Probe)	Wafer fabrication	Wafer level	Product functional test to verify each die meets product specifications.
Burn-In Reliability	Packaged IC	Packaged chip level	ICs powered up and tested at elevated temperature to stress product to detect early failures (in some cases, reliability testing is also done at the wafer level during in-line parametric testing).
Final Test	Packaged IC	Packaged chip level	Product functionality test

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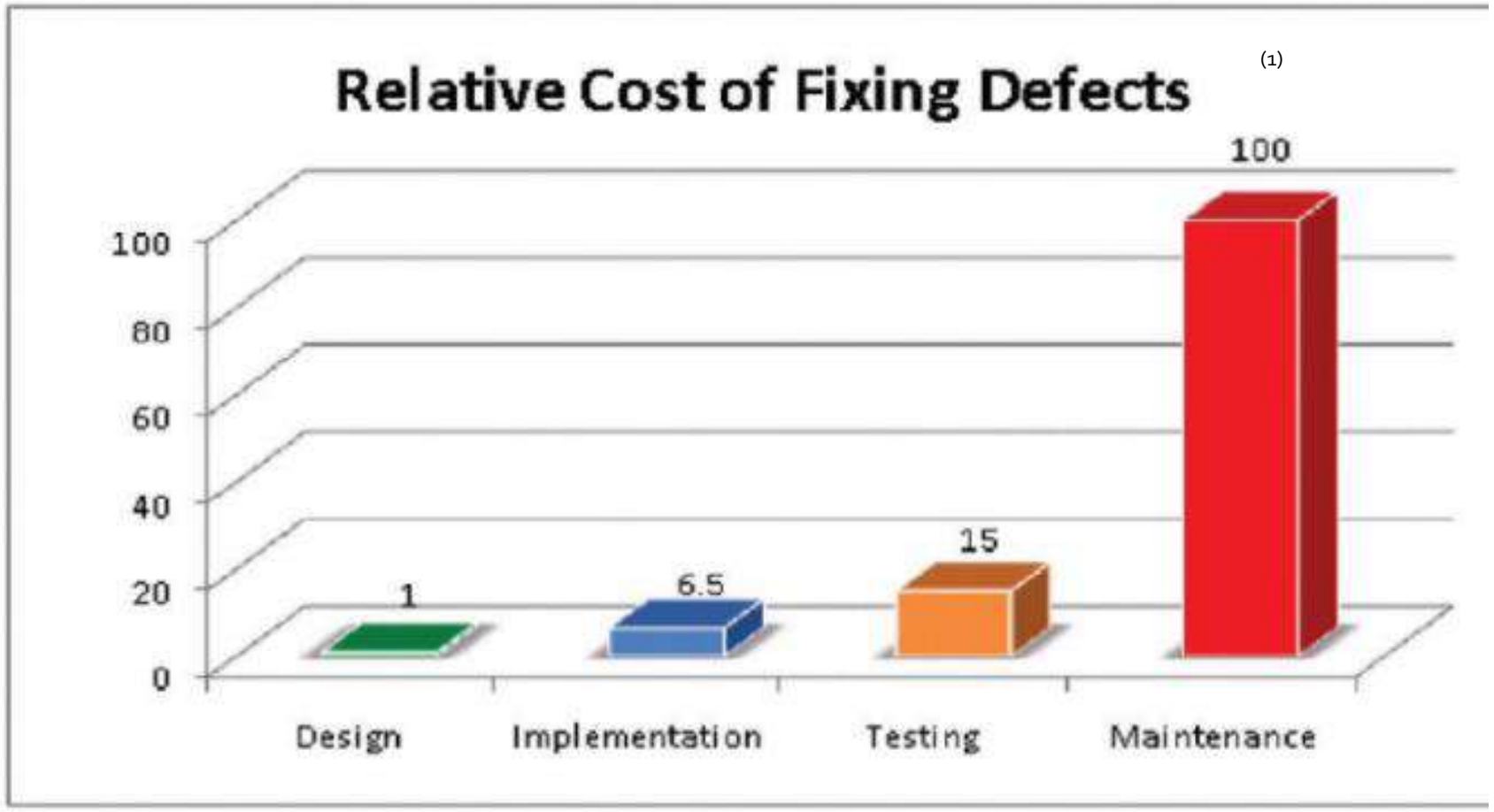
The Value of Test

- **Why test devices?**
  - The cost of return devices is much higher
  - Miniaturization complicates board rework, if needed to replace bad device
  - Manufacturers reputation is important due to competition
  - Consumer market expectations of high-quality product



(1) *Source: IBM System Science Institute Relative Cost of Fixing Devices*

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Known-Good-Die and Stacked Die Devices

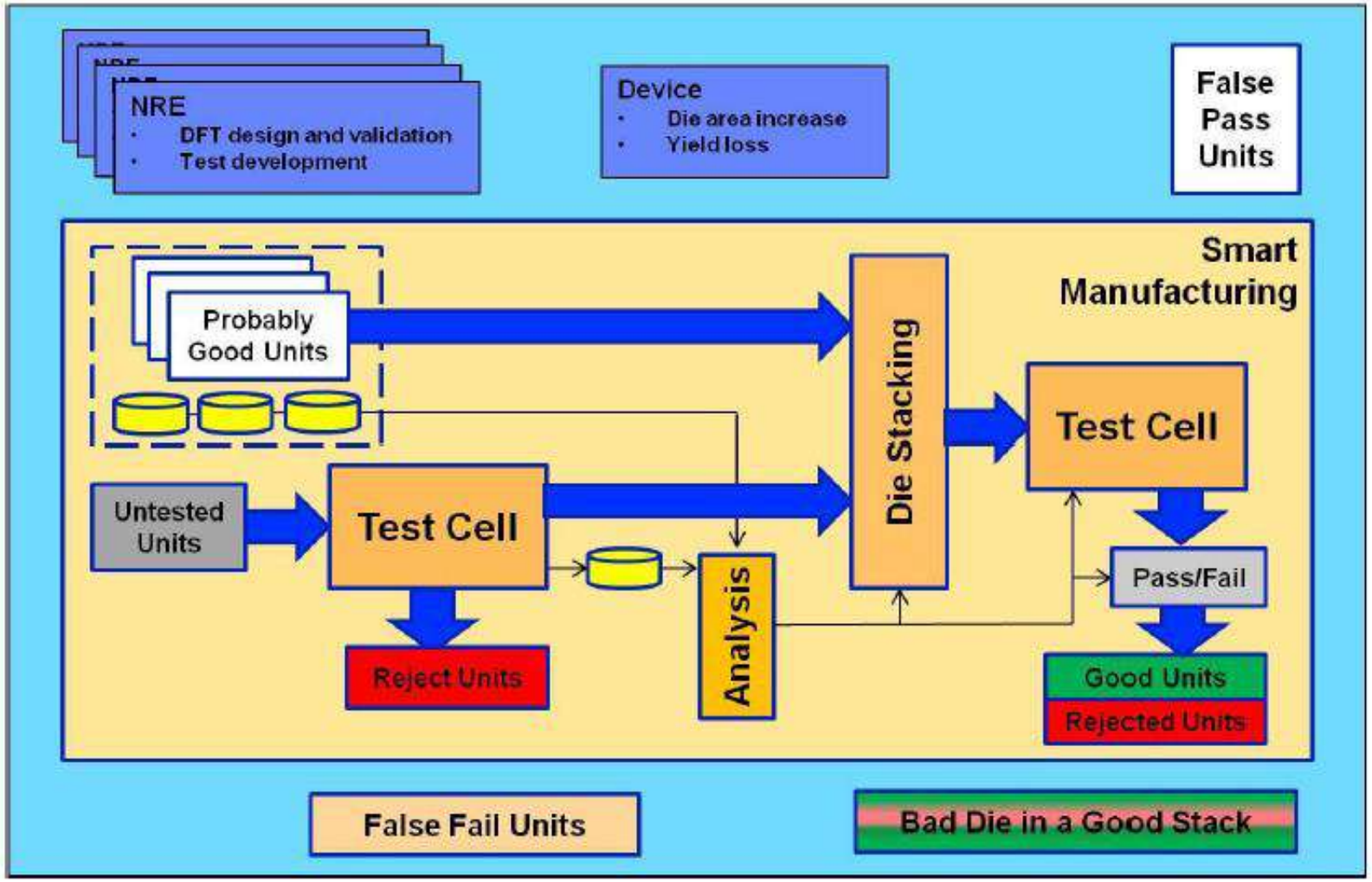

Figure TST1 - Smart Manufacturing Test Flow for Stacked Die Devices

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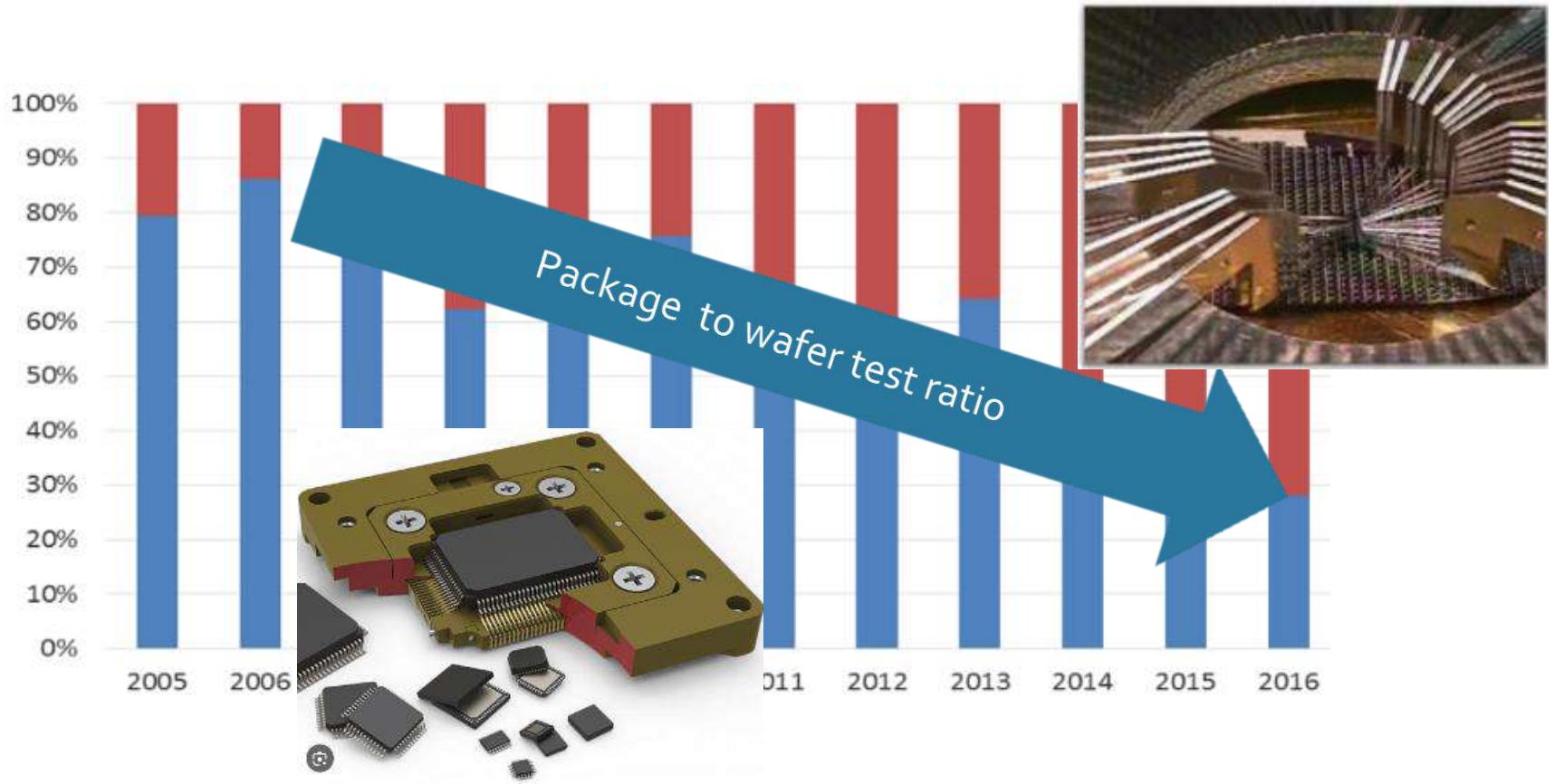
Transition to More Probe Test – Known Good Die

- Most ATE is sold for Probe Test
- Most AP and PMIC devices are trimmed at probe
- Major drivers are cost reduction or CSP/Fan-Out Packaging



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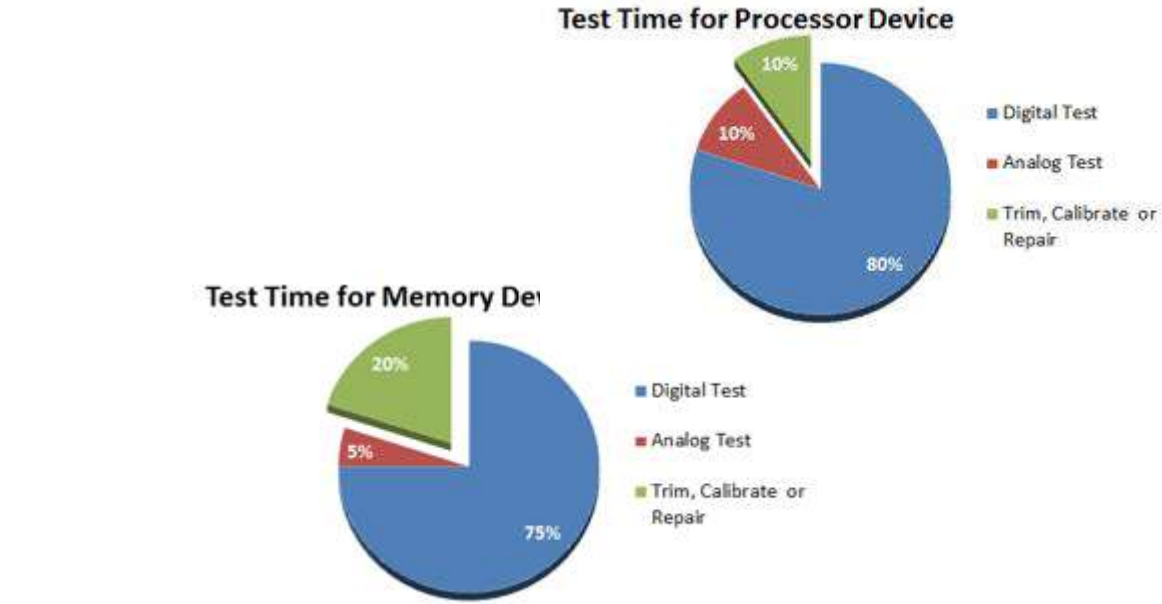
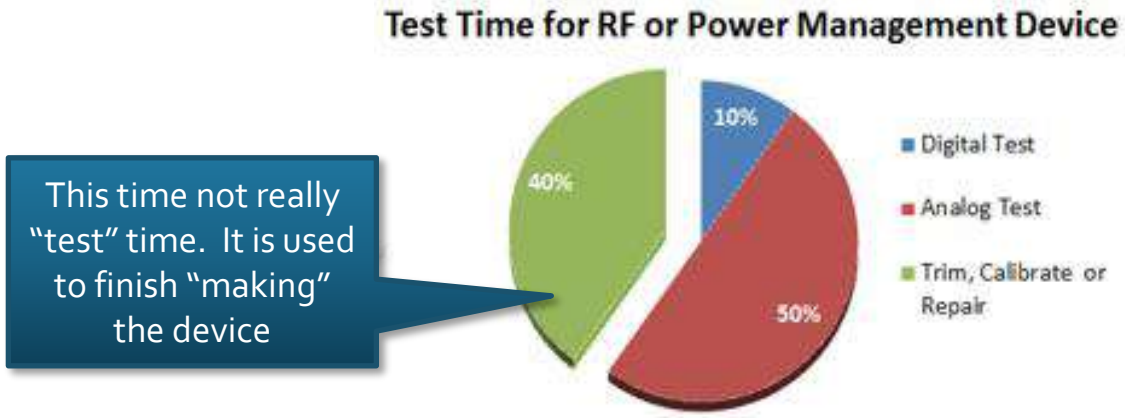
Save Defects More "Test" Now Includes More Functions

- "Test" is no longer just seeing if a part is good or bad
- It is part of the manufacturing process
  - Trimming/calibrating
  - Grading for speed, Accuracy, etc.
- In many cases, many devices would have zero yield if they didn't go through the trimming/calibration process
- This is a major *contributor to COT* (cost of "test") that is increasing and needs *some process/DFT or technology* change





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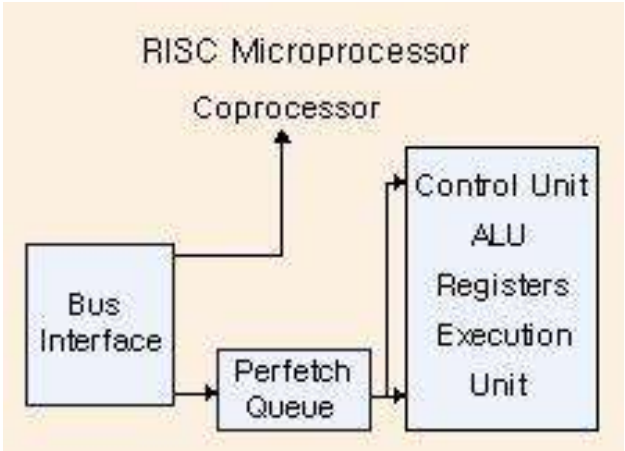
Structure of Automatic Test Equipment (ATE)

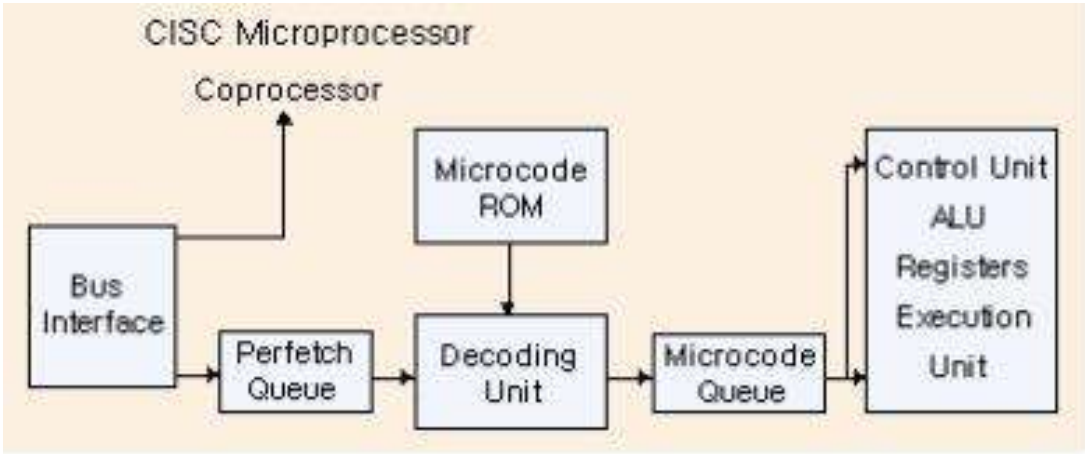
Test System Architecture

- 1960 : Integration of stacked independent options connecting through back born control bus
  - GPIB / IEEE-488 by HP from late 1960 and 1975

1961: Diode Tester D133 for Raytheon company

- 1970: Start to use a microcontroller to ATE - RISC vs. CISC controller
  - VXI from 1980
  - PXI from 1992
  - LXI -Standard defines the communication protocols for instrumentation and data acquisition systems using Ethernet. Proposed in 2005 by Keysight
  - JTAG/Boundary-scan IEEE Std 1149.1
  - USB (380MBS) and RS-232





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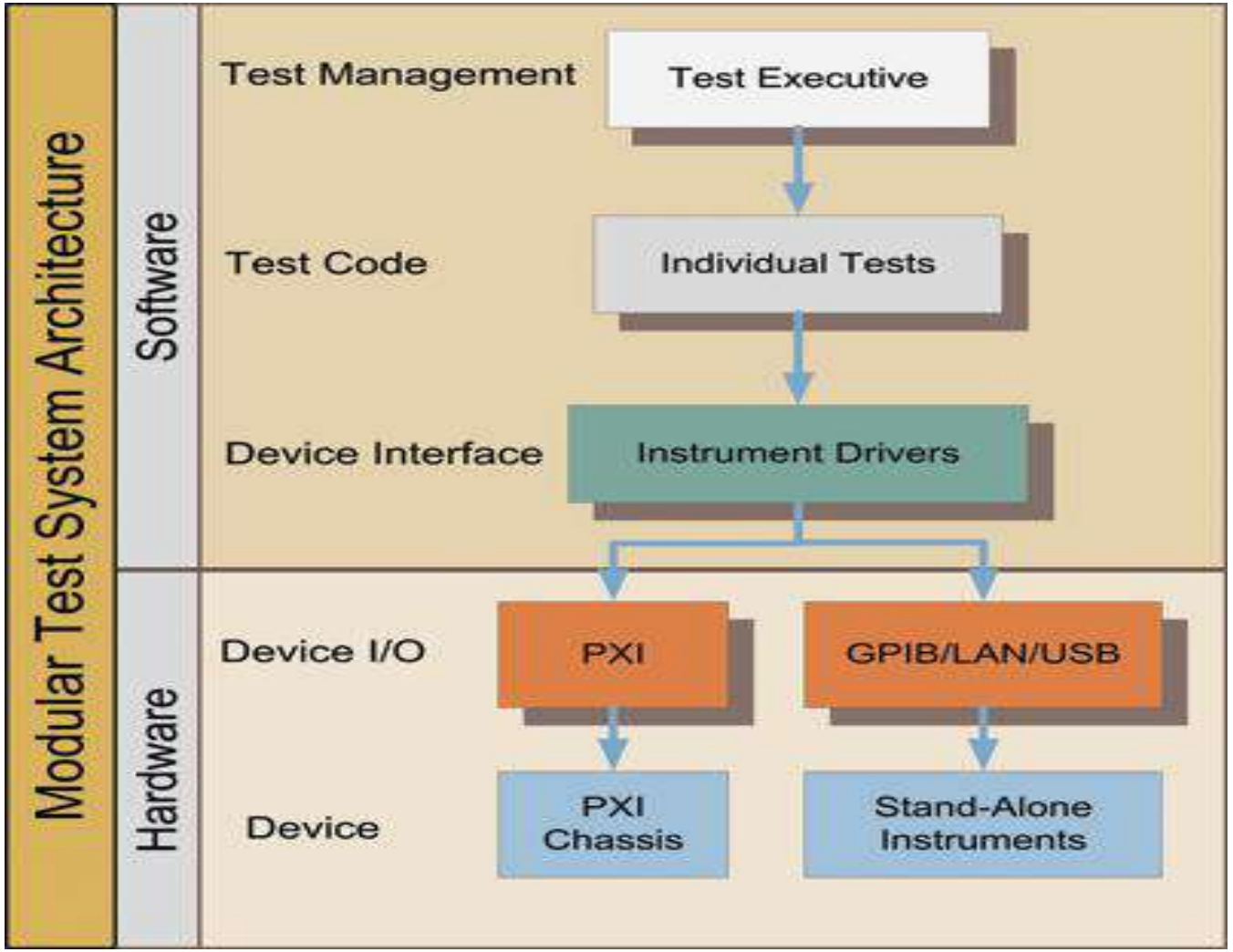
Test System and Resources



PXI

PCI

LXI

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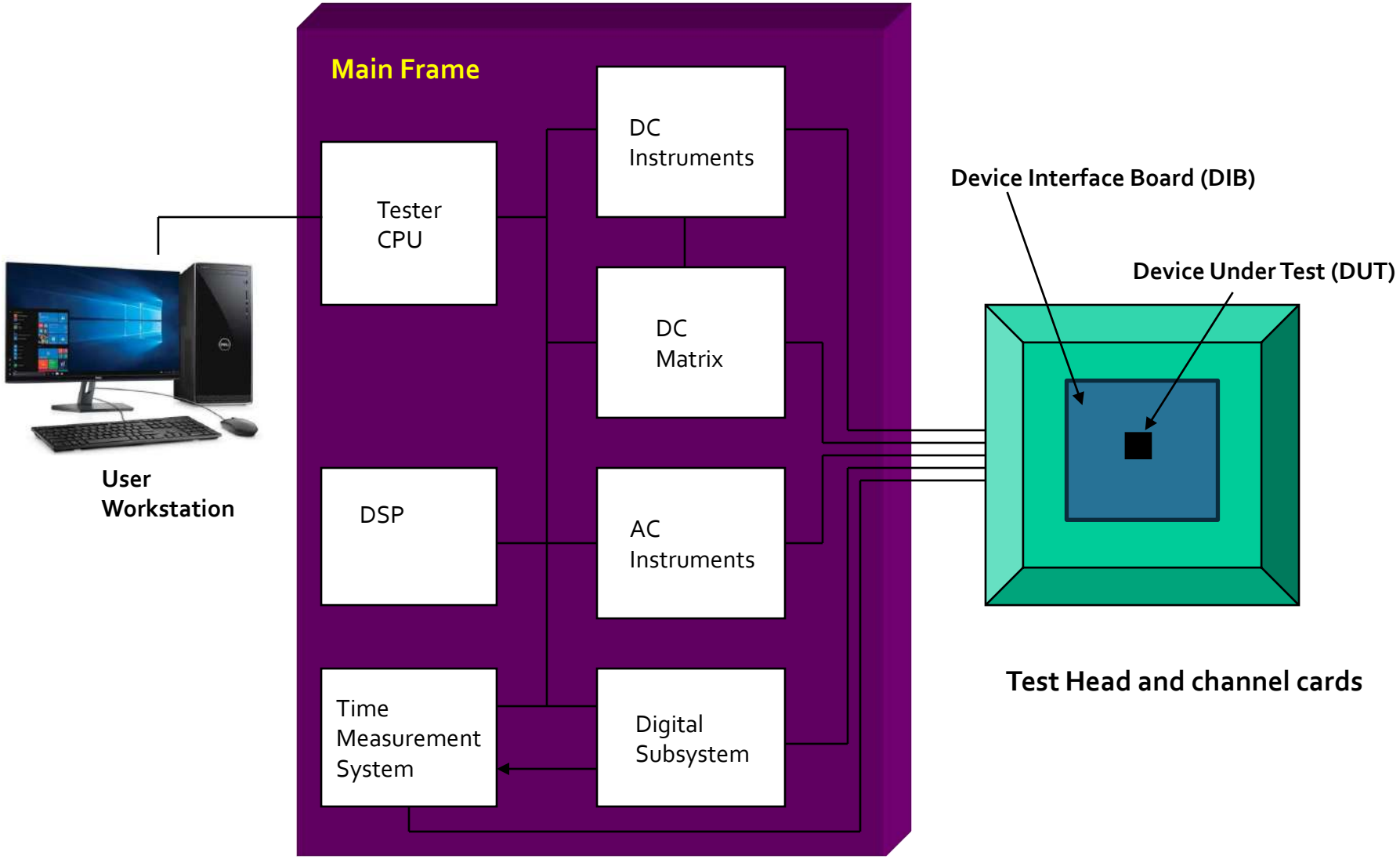
Mixed Signal Test System (1970's-1980's



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ATE System Architecture

- **Main kiosk**
  - Main power supply unit
  - Reference Clock source
  - User computer and Test computer
    - RISC based or CISC based
  - System cooling solution
    - Air cooling or Liquid cooling
- **Test head**
  - Fast timing and control bus – pattern control
  - High Speed Data transfer bus to DSP
  - High performance multi-core DSP
    - Background signal move and processing)
    - Producing fast, stable and repeatable test results
- **Calibration option**
  - TDR, DC, AC, RF, Skew, Capacitance
- **DIB and PIB**

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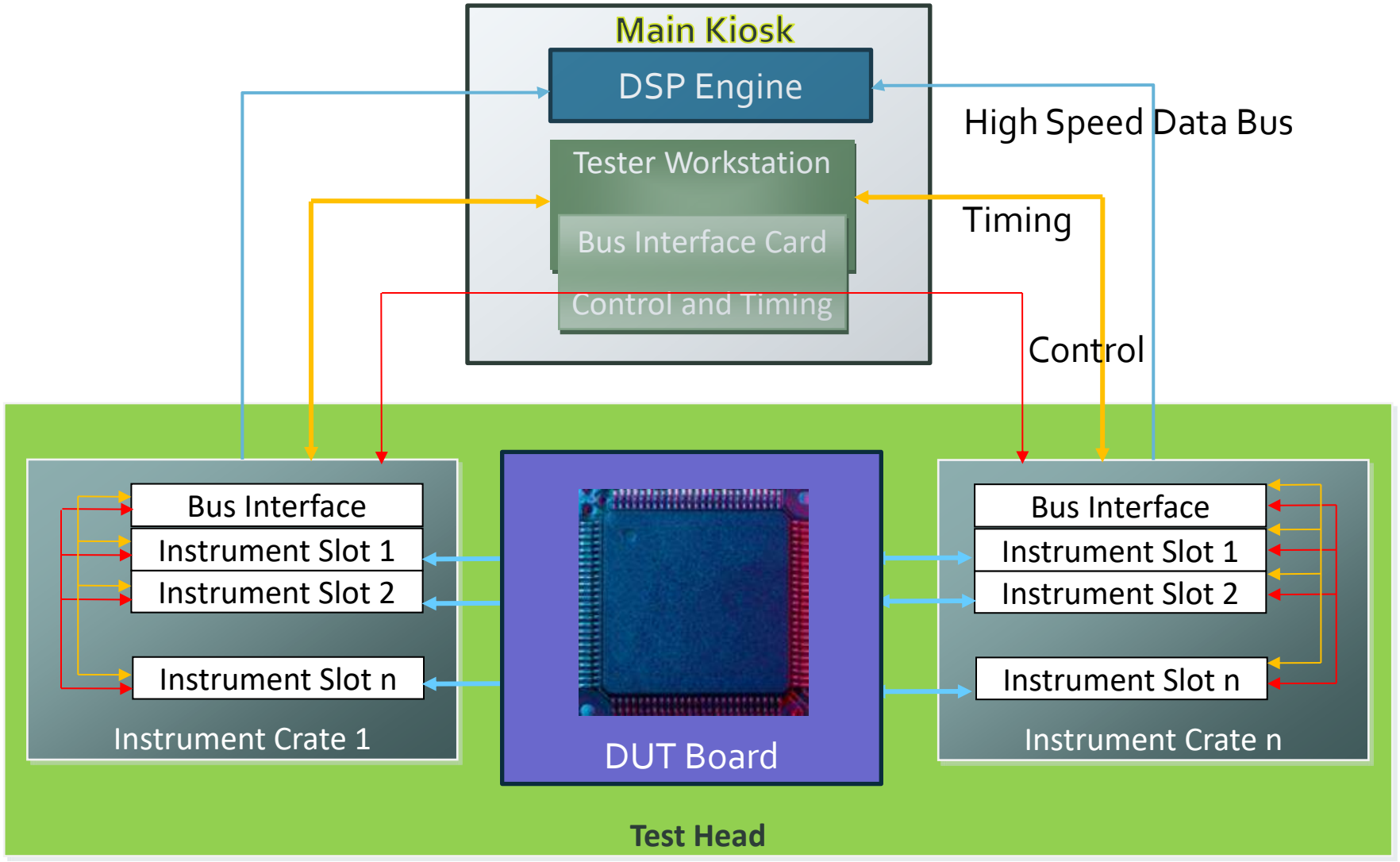
SoC Test with General Universal Instrument Slots



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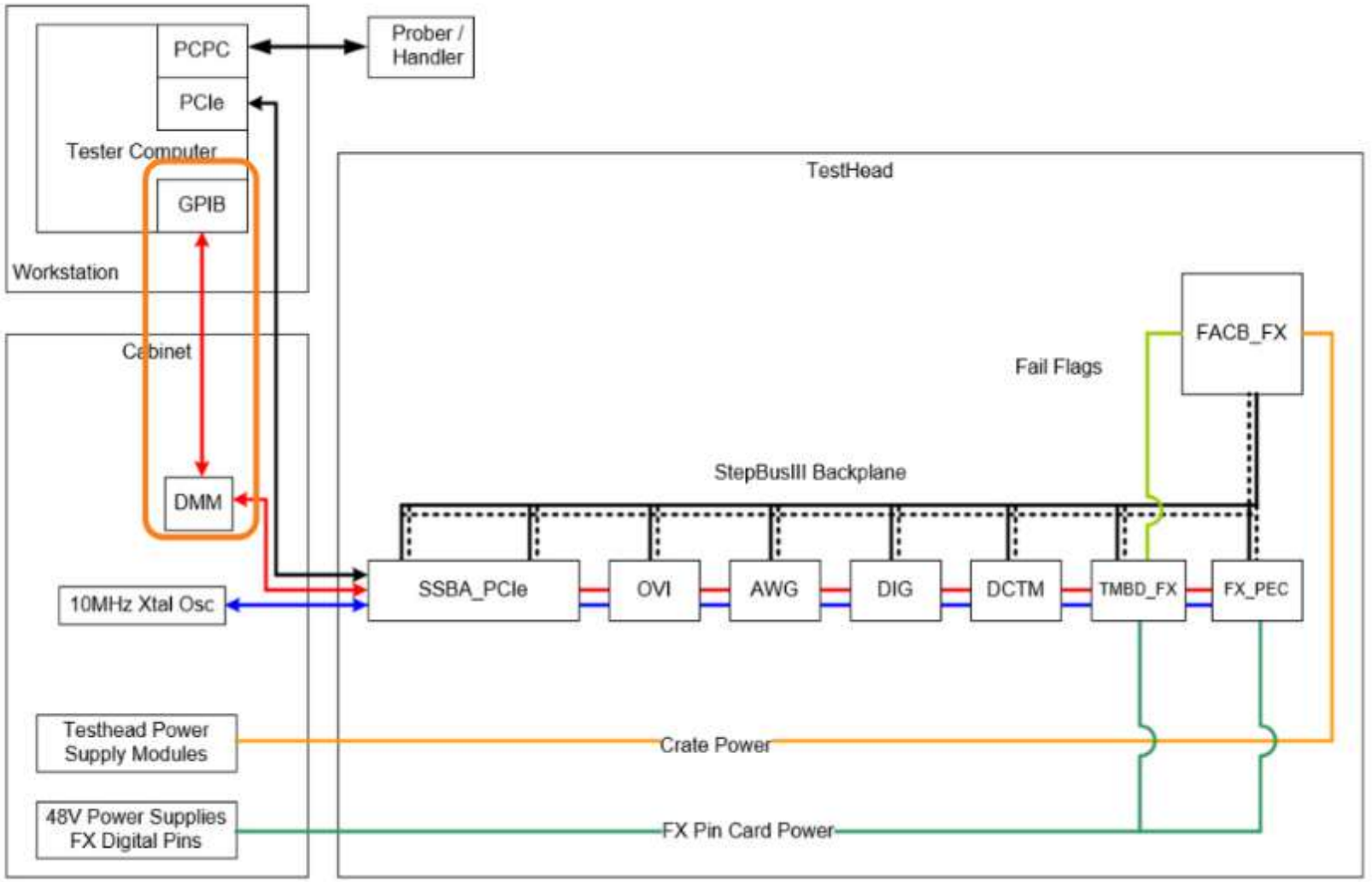
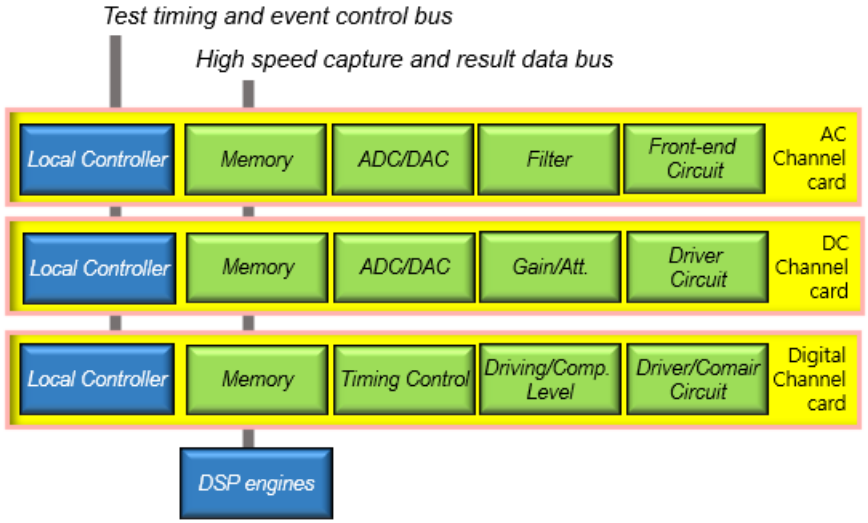
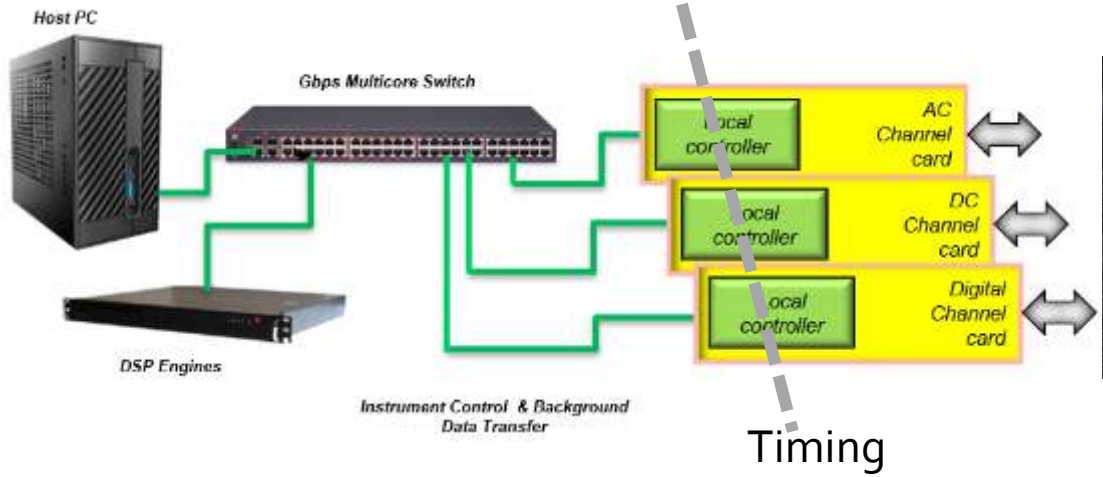
Test System Communication



Modern ATE System Architecture



- **Fast Timing and control bus to integrate the individual options precisely**
- **High-speed data transfer bus to DSP**
- **High-performance multi-core DSP engine for handling the data fast and 100% background**
- **For producing fast, stable, and repeatable test results**



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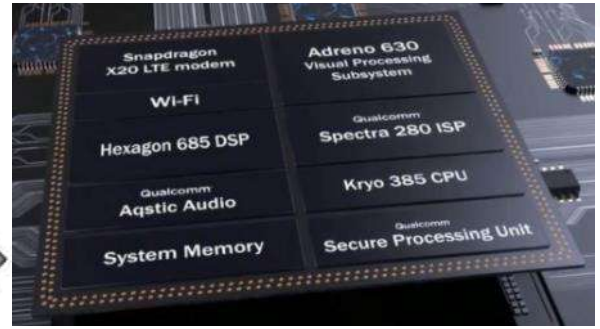

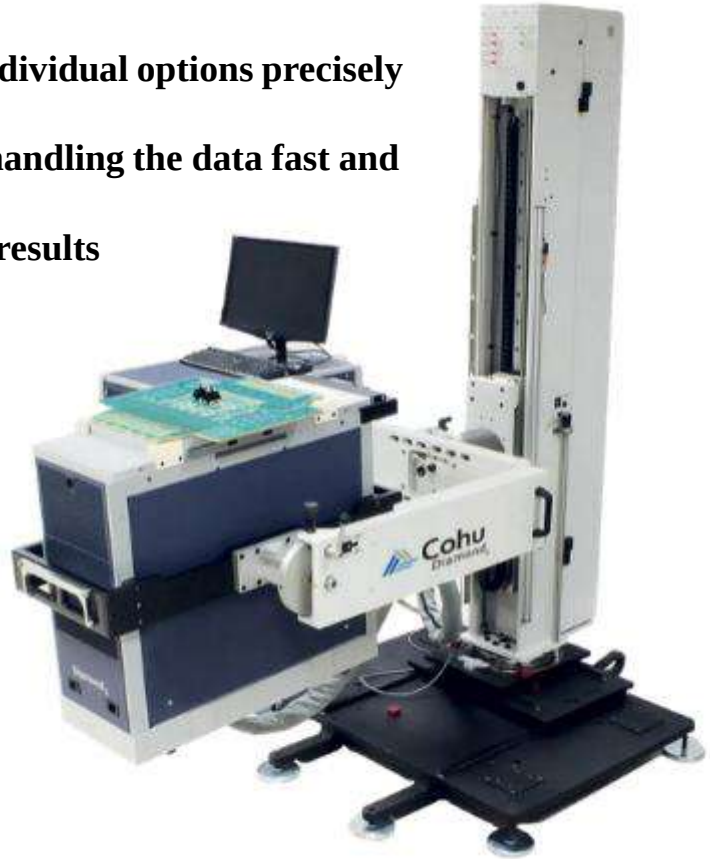

(1) *Source: Qualcomm*

Example Diamondx Single and Dual Test Heads

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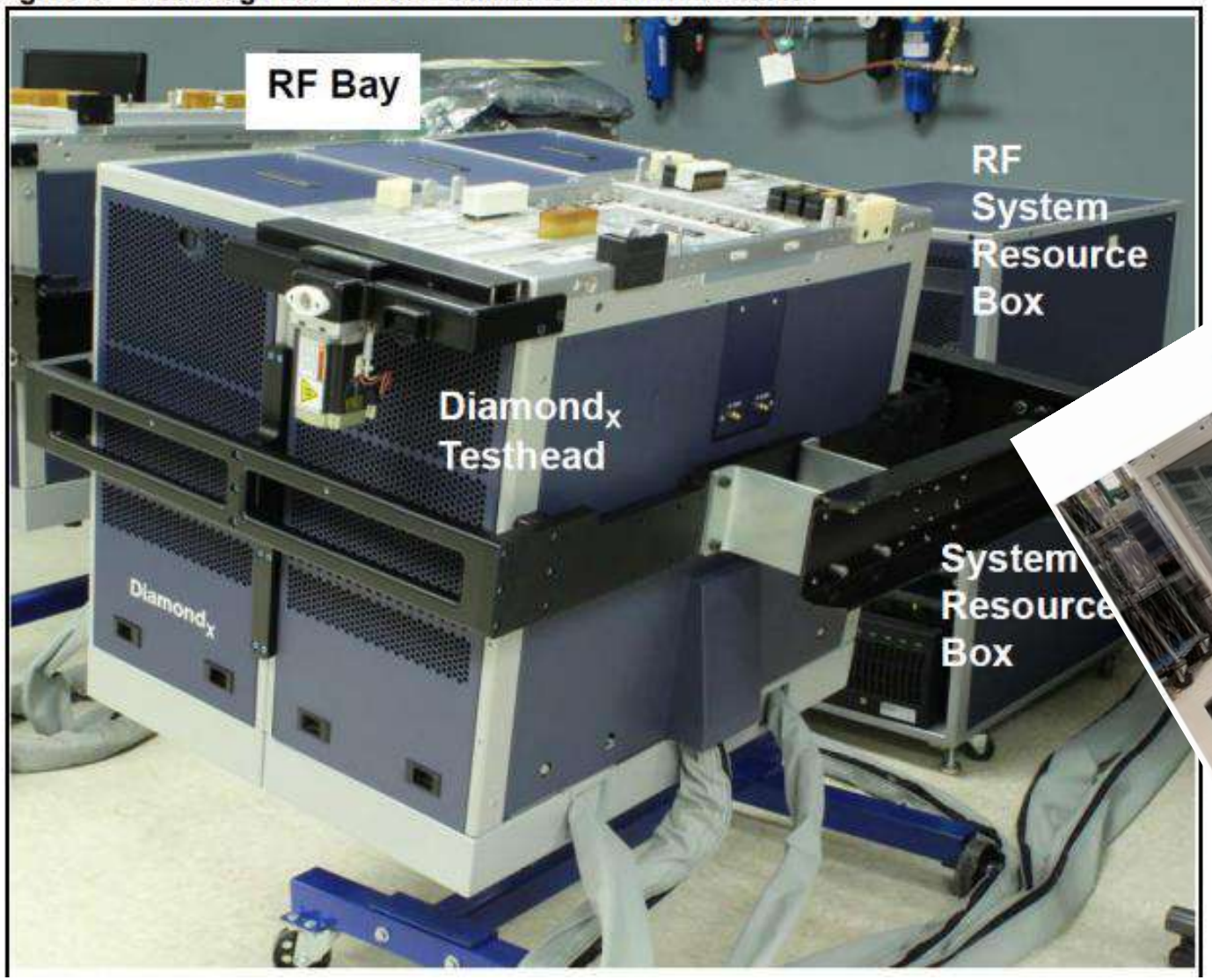
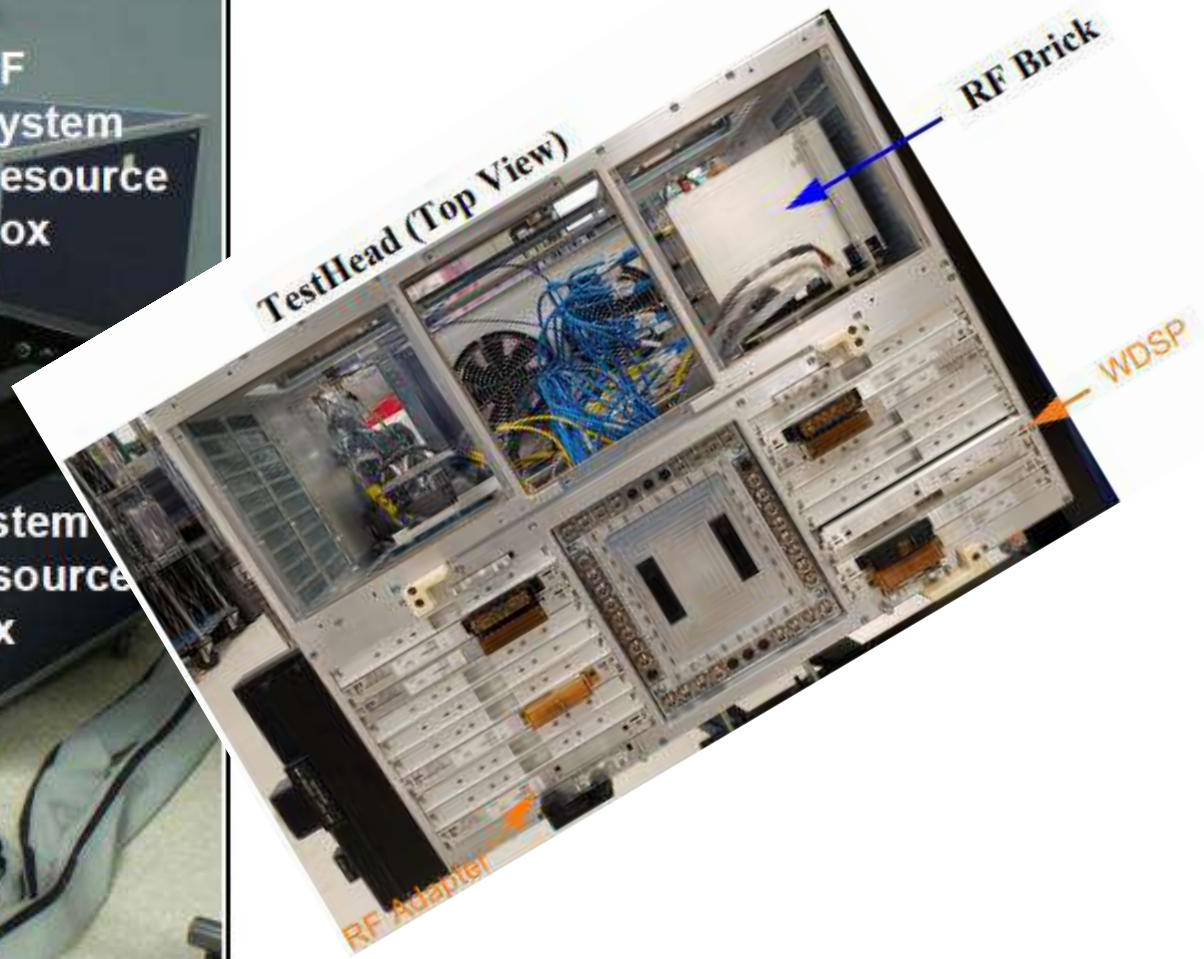
Example Diamondx Configuration with RF option

Figure 6. RedDragon RF Brick installed on Diamondx tester





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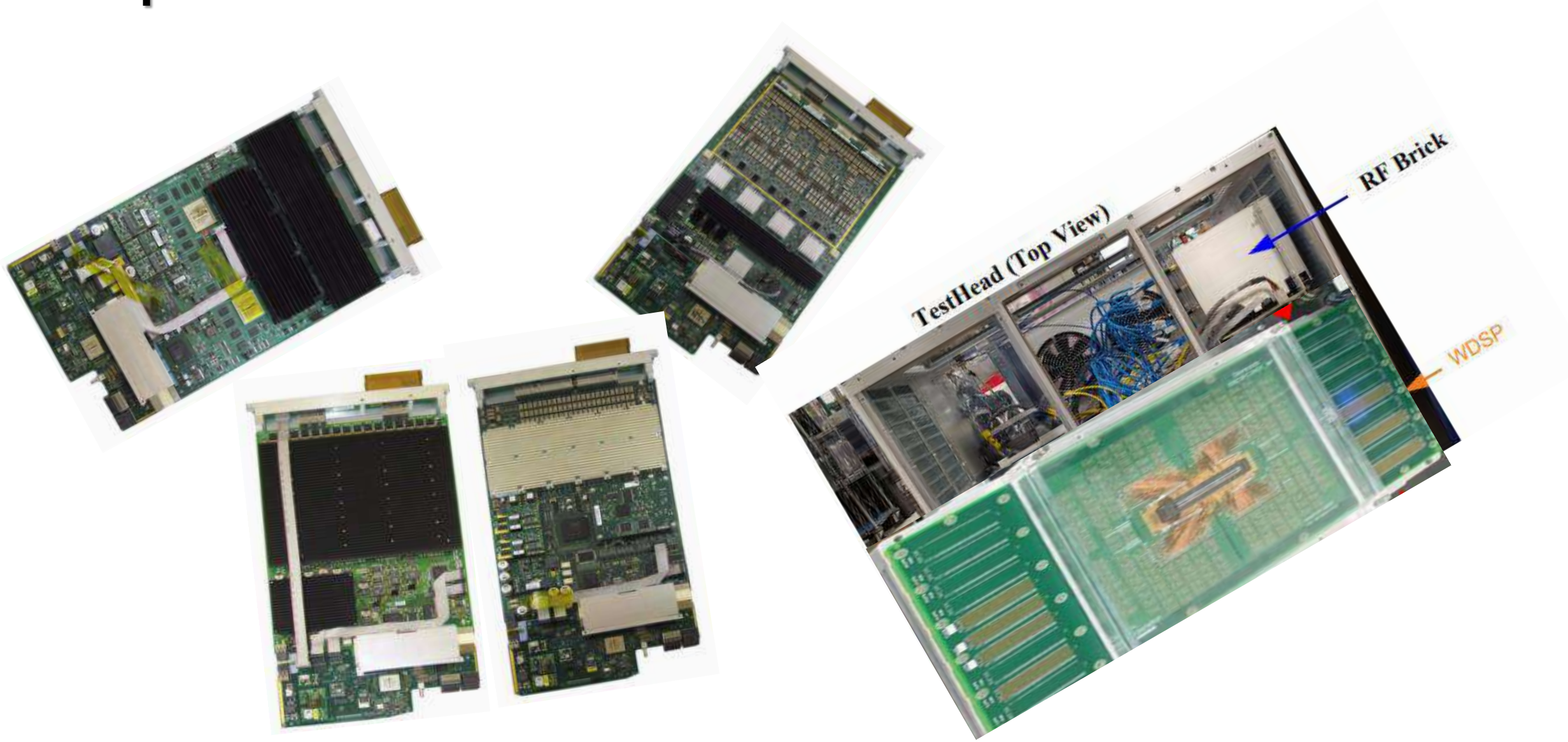
Example Diamondx instruments



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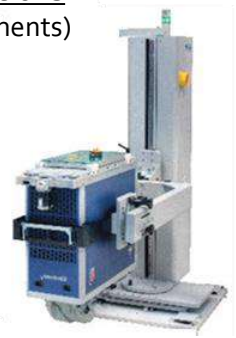
Diamondx – Broad set of instruments in a scalable platform

Lightweight Configurations
(2-8 Instruments)

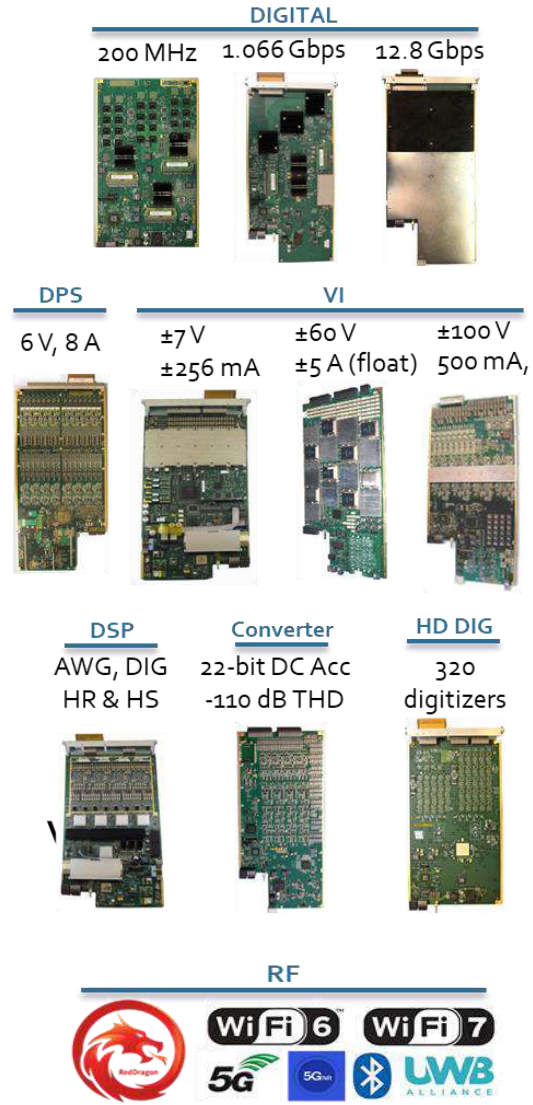


Workhorse Configurations
(15-20 Instruments)

Heavyweight Configurations
(30-40 Instruments)

Current deployment:
>1,100 systems worldwide
w/ ~60% at OSATs

- 5, 20 and 40 slot scalable infrastructure
  - *Capable of >7,000 resources*
- Full-featured high-density instrument suite covering digital, analog, DSP & RF
  - *Digital: Up to 192 ch/bd*
  - *VI: Up to 72 ch/bd*
  - *RF: Up to 32 Universal Ports*
- >99% parallel test efficiency
- Low noise floor
- Top-Hat transforms load board circuitry into tester resources
- Instancing improves UPH at existing site count *[Coming in 2024]*



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Test System Diamondx – Digital Multimeters

Keysight / Agilent 34401A Digital Multimeter, 6½ Digit

The Agilent Technologies 34401A multimeter gives you the performance you need for fast, accurate bench and system testing. The 34401A provides a combination of resolution, accuracy and speed that rivals DMMs costing many times more. 6½ digits of resolution, 0.0015% basic 24-hr dcV accuracy and 1,000 readings/s direct to GPIB assure you of results that are accurate, fast, and repeatable.

Features:

- 6½ digit resolution to 100 nV, 100 µΩ, 10 µHz
- Accuracy 0.0035% for DC, 0.06% for AC (1-year)
- True RMS AC Volts and Current
- 2- or 4-Wire Ω, Frequency/Period, Continuity, Diode Test
- 1000 readings/sec across the GPIB
- GPIB (SCPI) and RS-232 included

Please see Datasheet for complete details and specifications.

❑ For more information, refer to multimeter manual that accompanies Test Syst

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ATE for Engineering or Small Production Configurations

❑ Use in regular office or small lab space

- Minimal footprint, power and cooling requirements allows use in engineering office space

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Test Cell – Tester and Handler Docking

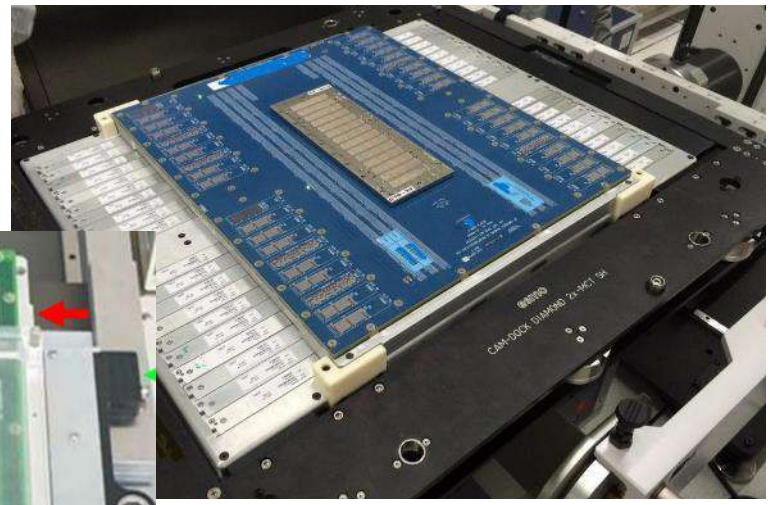
Test Cell (another example)

Load Board & Probe Card

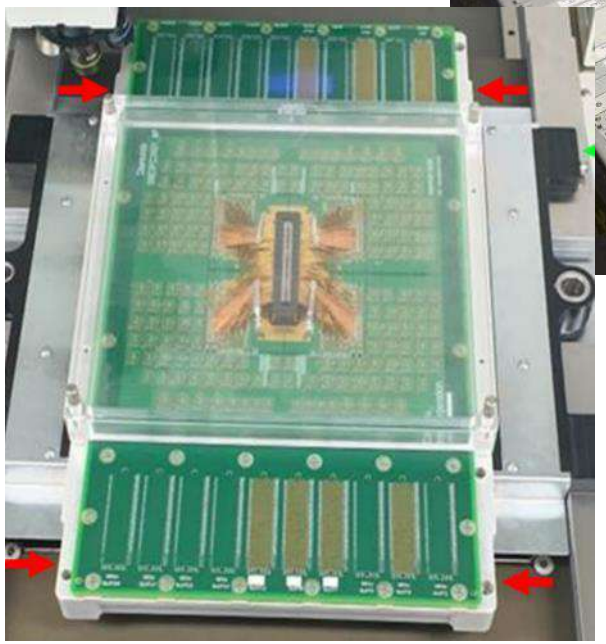
- **The interface between the tester and the DUT is through Printed Circuit Boards:**

1. **Load Board or DIB**
   - DIB stands for Device Interface Board
   - Interface for Packaged Parts

2. **Probe Card or PIB**
   - Also called PIB (Prober Interface Board)
   - Interface for Wafers



Load Board



Probe Card

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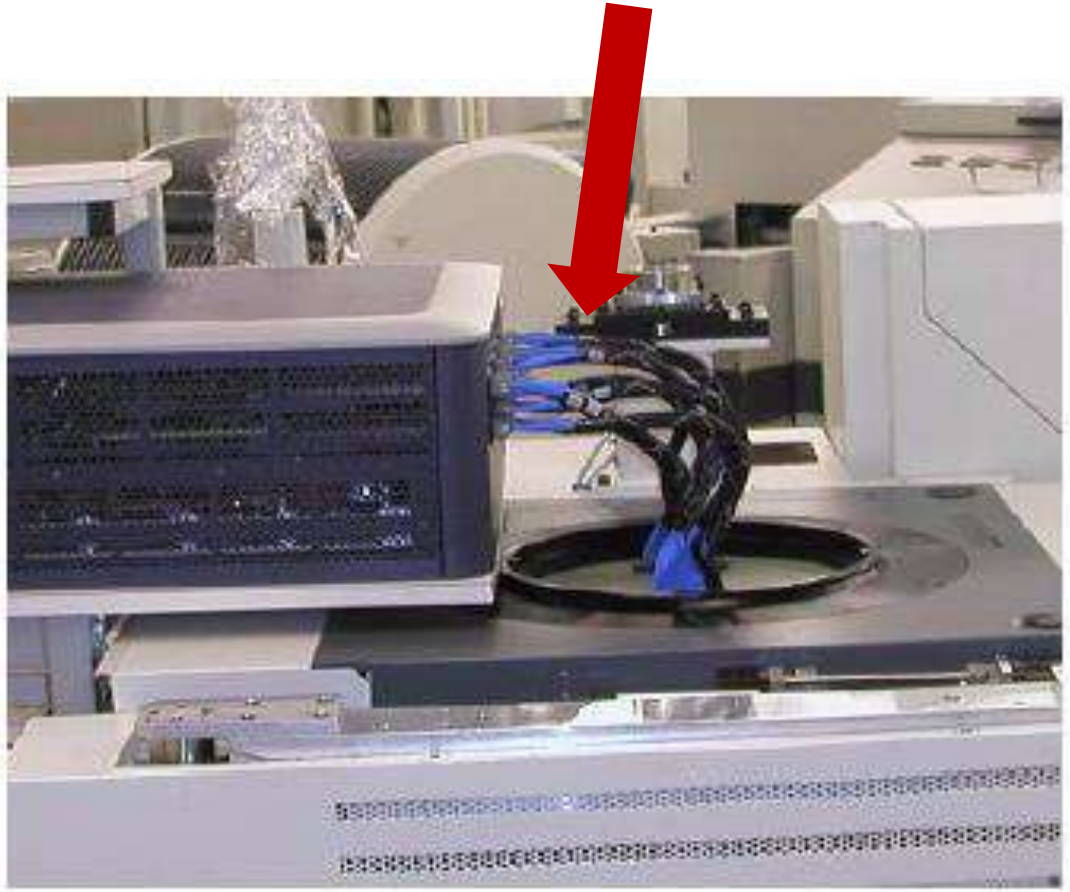
Mechanical Mounting of Test Head to Handler/Prober

- "Soft Docking" or "Cable docking".



Hard-dock

Requires precision mechanical alignment and clamping hardware.

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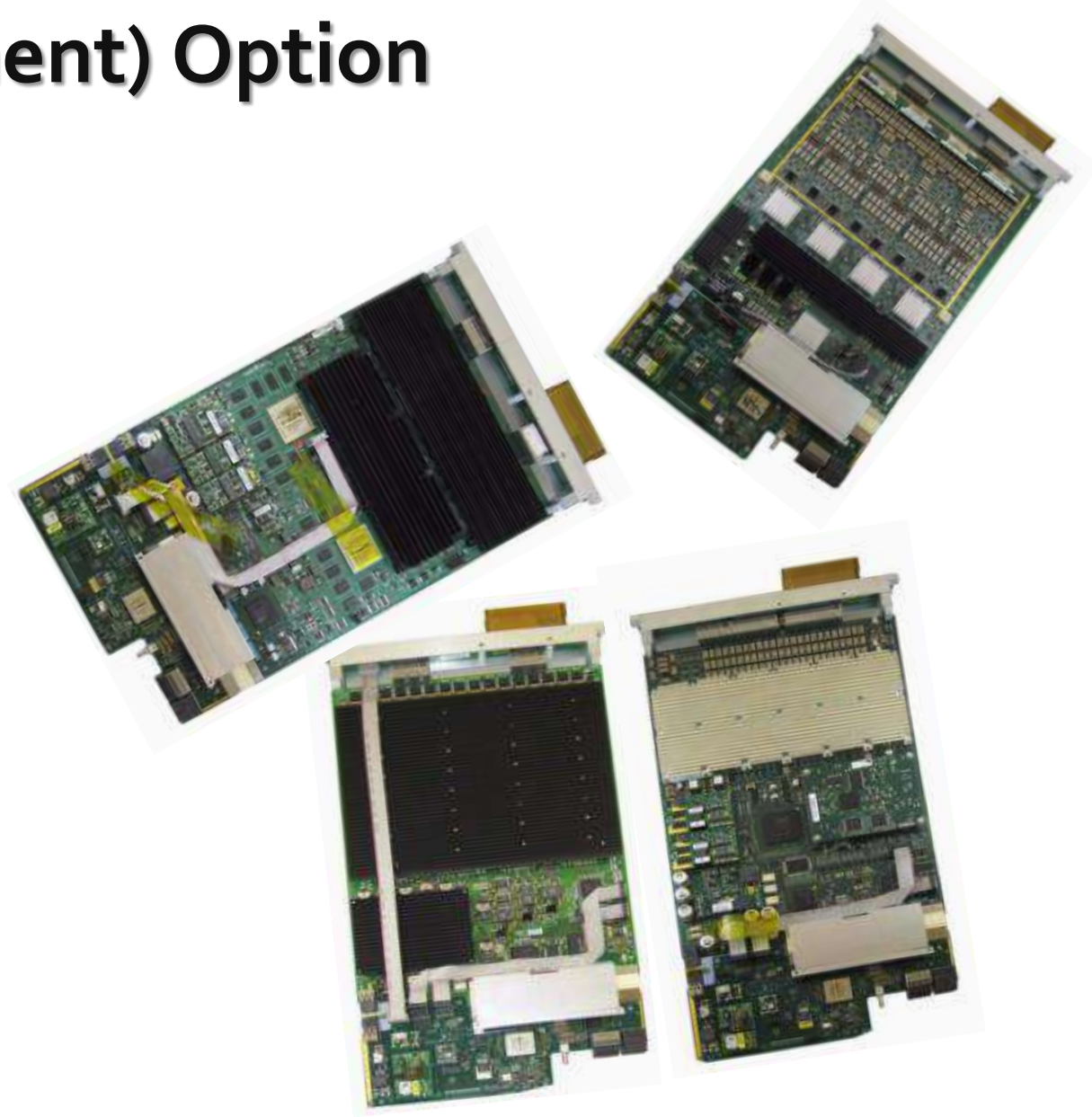
ATE (Automatic Test Equipment) Option

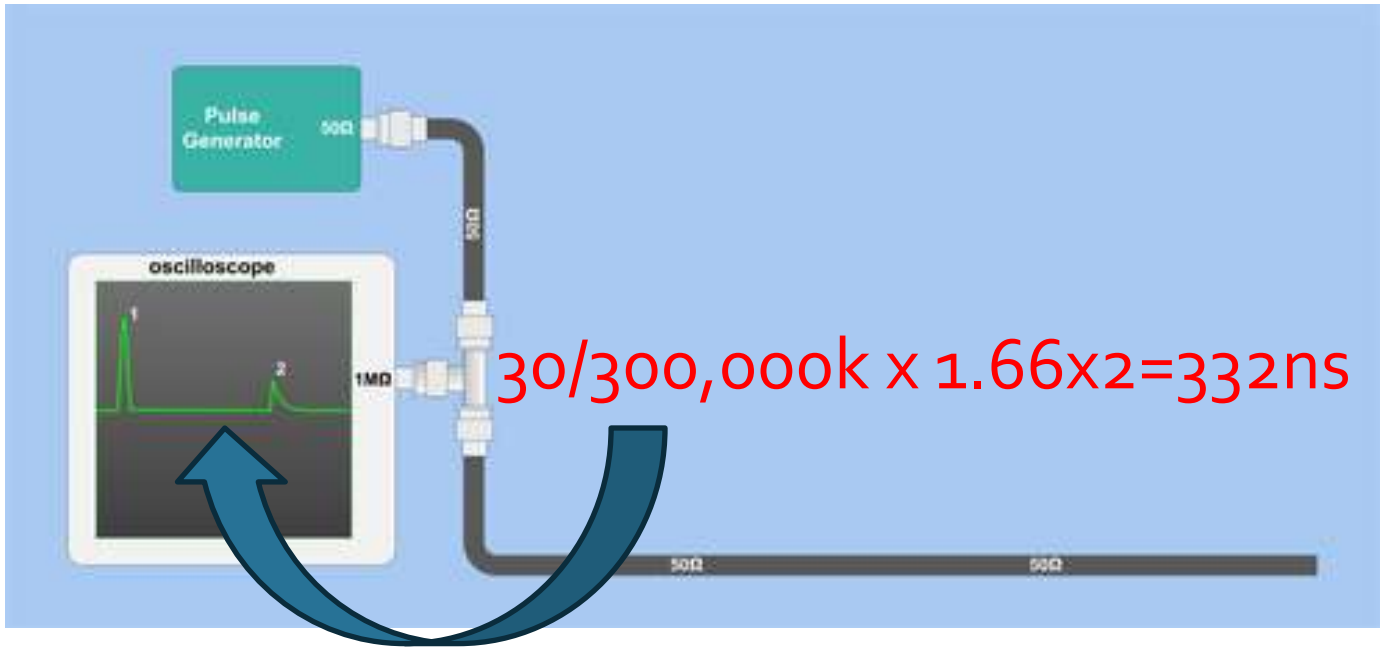
- DC source and meter
  - High current and voltage
  - High accuracy and stability
  - Current and voltage serge protection
  - High speed slew and stability
  - Higi Power option
  - AWG signal sourcing and capturing capability
- AC AWG Signal source and capture
- RF Signal Generator and Capture
- Digital I/O pattern generation and capture
- High Speed Digital I/O interface – SerDes, MiPi
- Memory test option ALPG
- Time Measurement

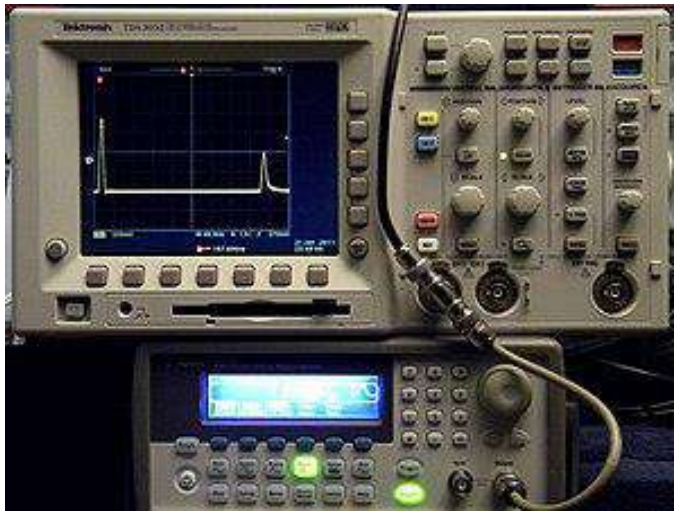


Advanced ATE Technology

Time-domain Reflectometer (TDR) for Digital Channel Skew

- Electronic instrument used to determine the characteristics of electrical lines by observing reflected pulses
- Used for matching line delay for a few 1000 digital channel in ATE system within few pico sec





Simple TDR made from lab equipment

1. 100 feet (30 m) of coaxial cable
2. impedance of 50 ohms.
3. The propagation velocity of this cable is approximately 66% of the speed of light in a vacuum.

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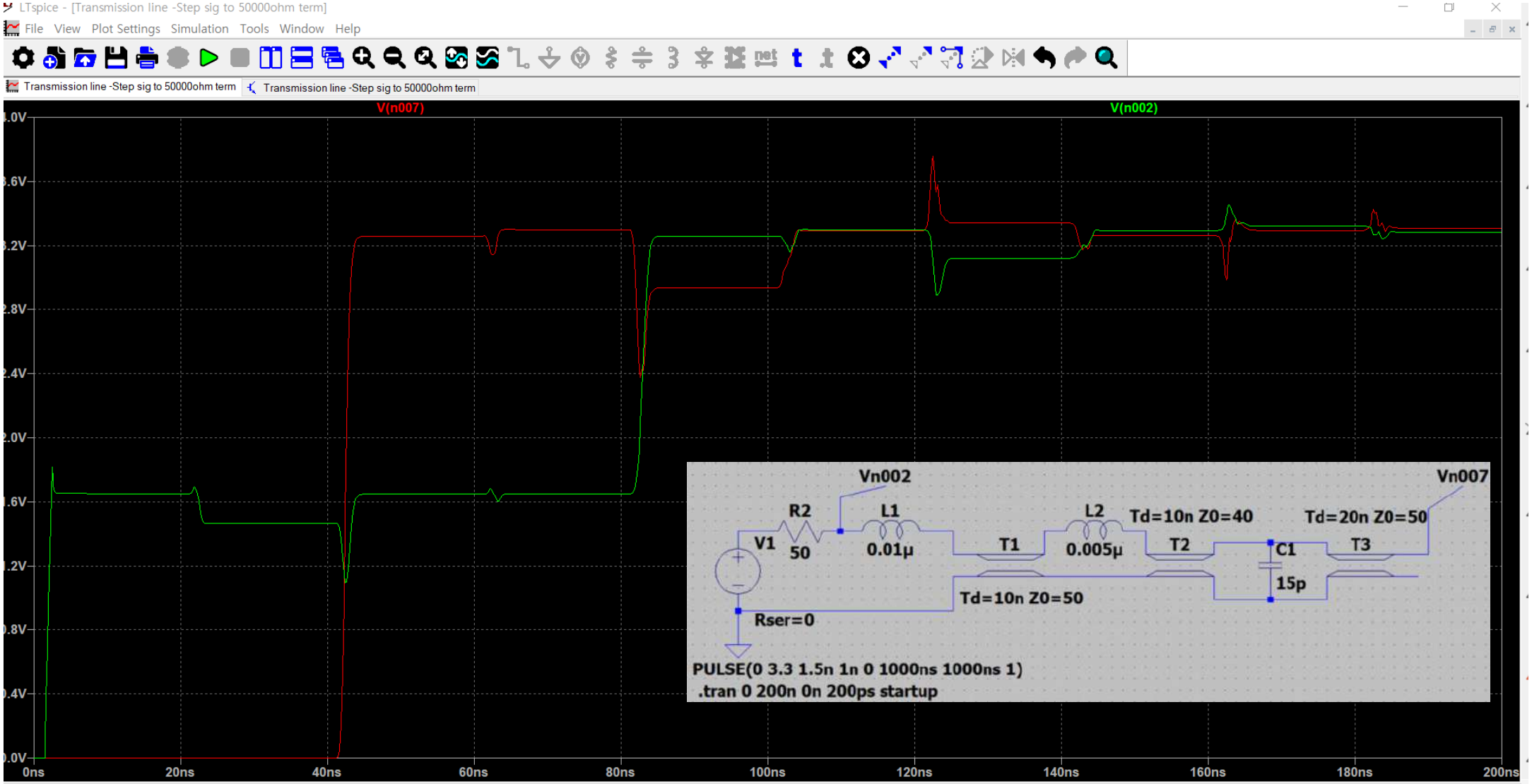
LT Sim Step Pulse & 200ns Delay 50-ohm Transmission Line



Shielding and Guarding Structure

- How to deal with Shielding and Guarding for device applications to reduce noise or leak

(Analog device application not an-347)

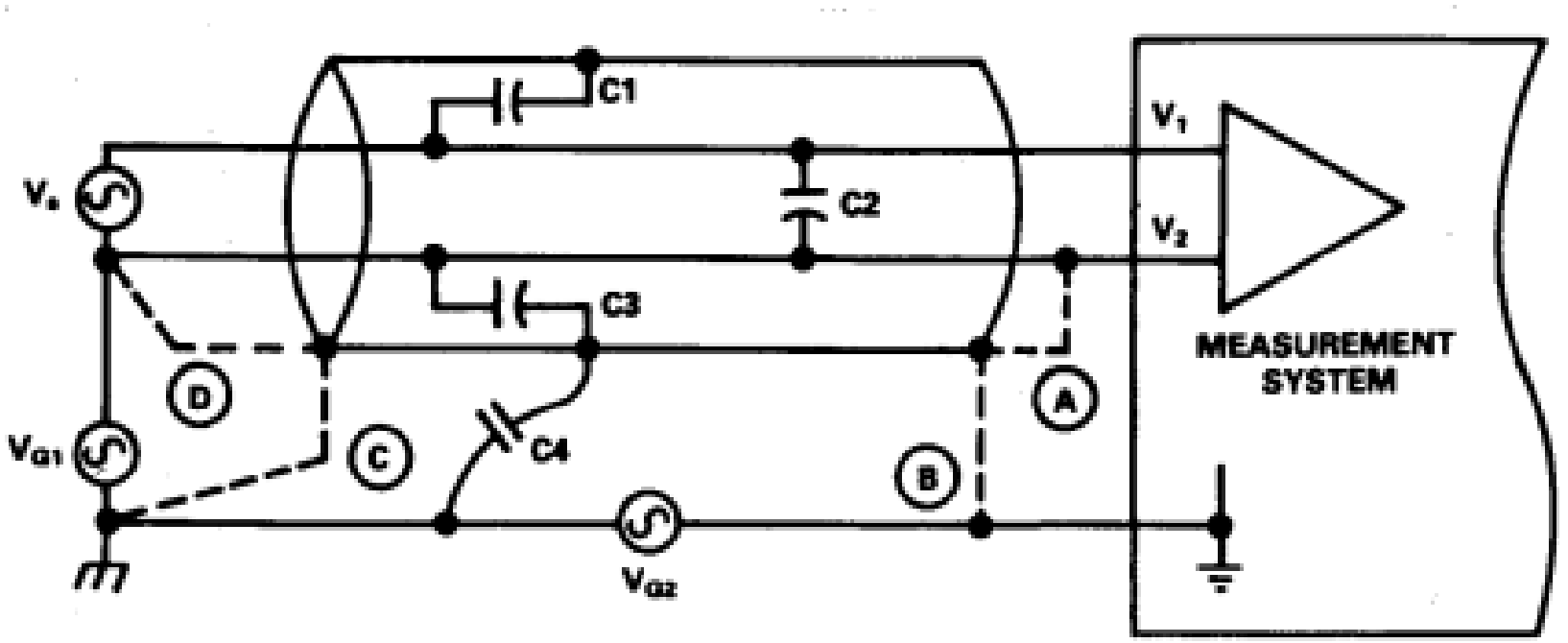


Figure 12. Possible grounds where system and source have differing ground potentials.

Circuitry to Provide a Guarded (Triaxial) Output

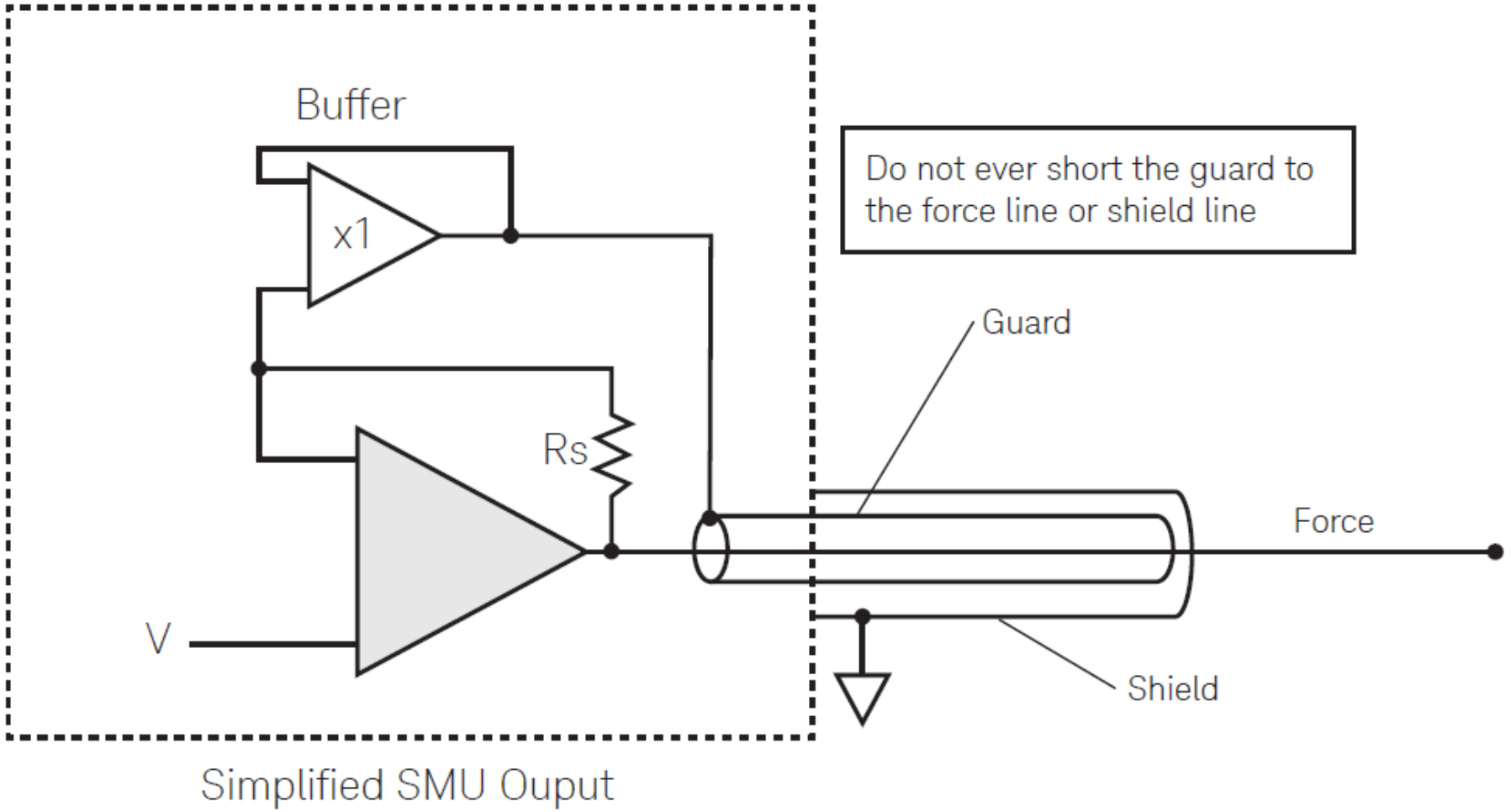
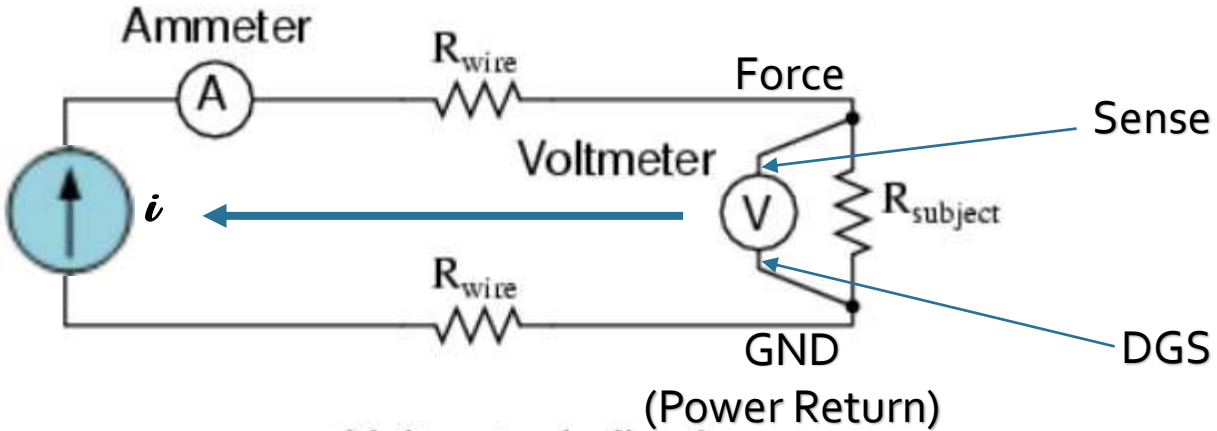


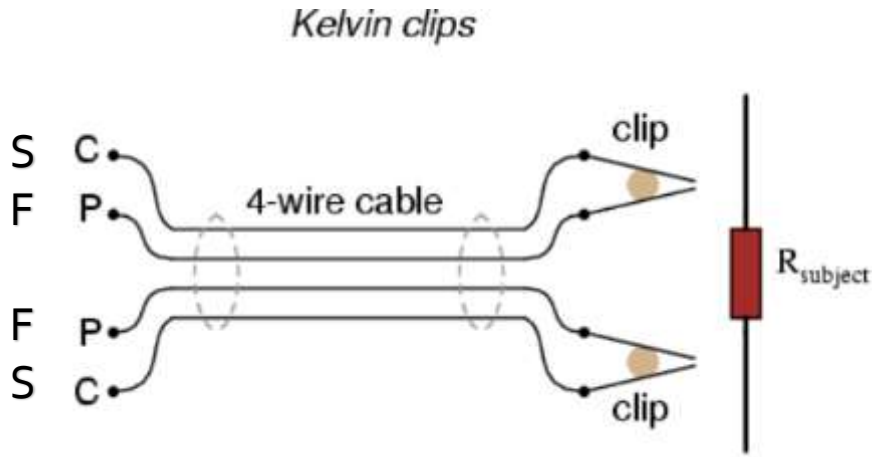
Figure 2.9. Circuitry to provide a guarded (triaxial) output.

DC – Kelvin Connection for Accuracy of Testing

Accurate Voltage/Current Driving and Measuring application



$$R_{subject} = \frac{\text{Voltmeter indication}}{\text{Ammeter indication}}$$



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DC – Kelvin Connection for Accuracy of Testing

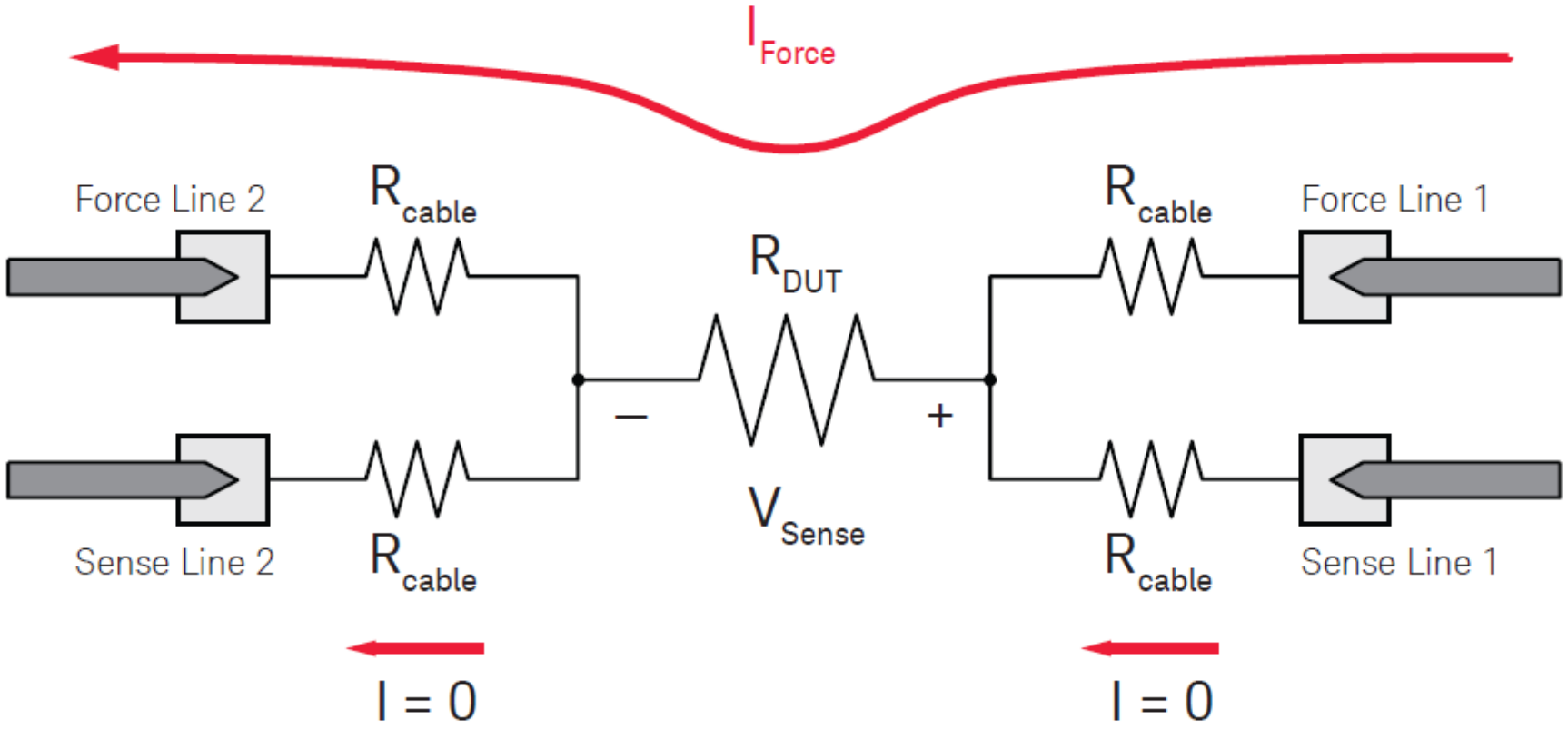

Figure 2.15. A Kelvin (or 4-wire) voltage measurement eliminates the effects of cable resistance by separating out the lines carrying the force current from the lines sensing the voltage.

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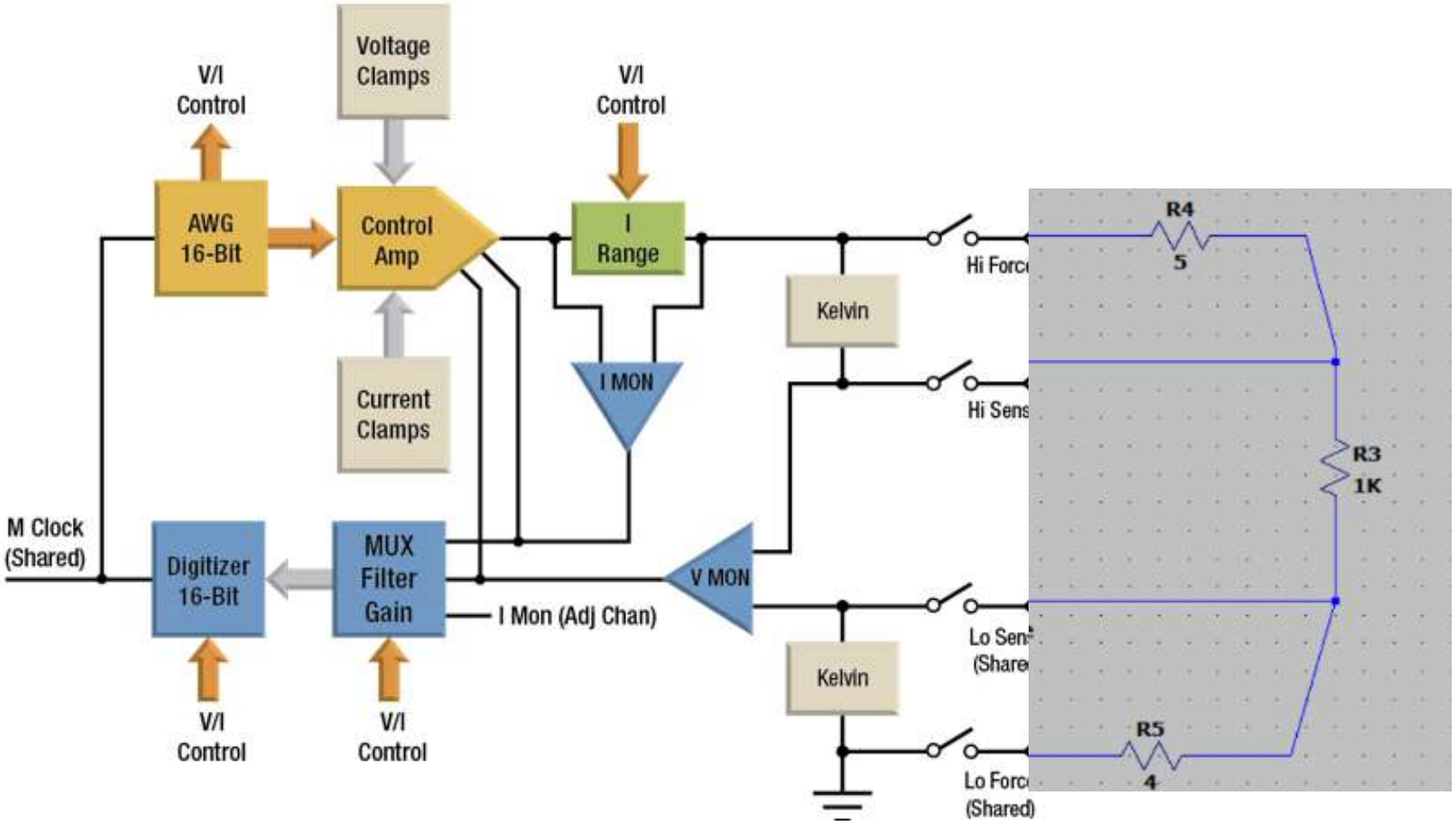
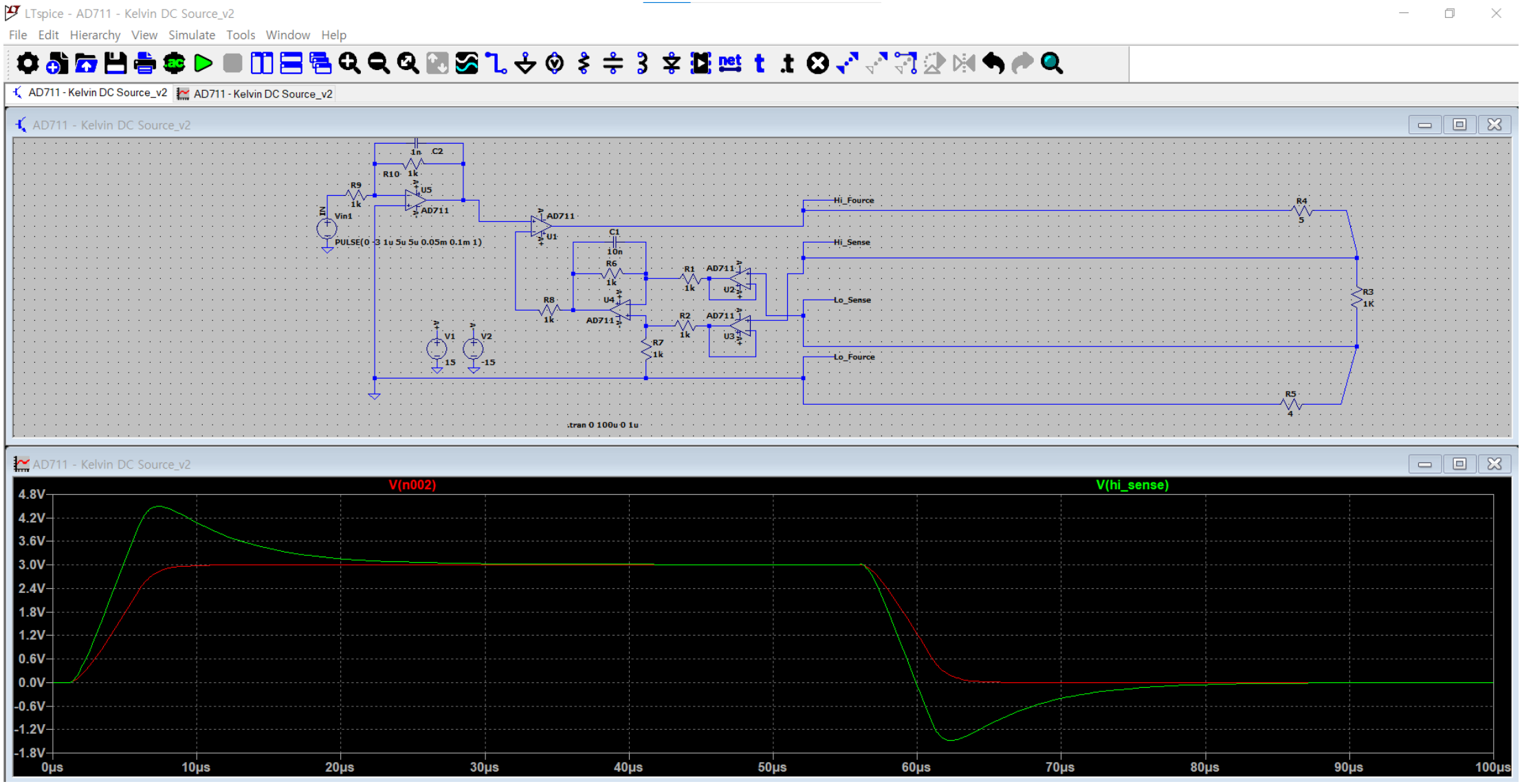
Kelvin Power Supply



Kelvin Power Supply and Slew Control



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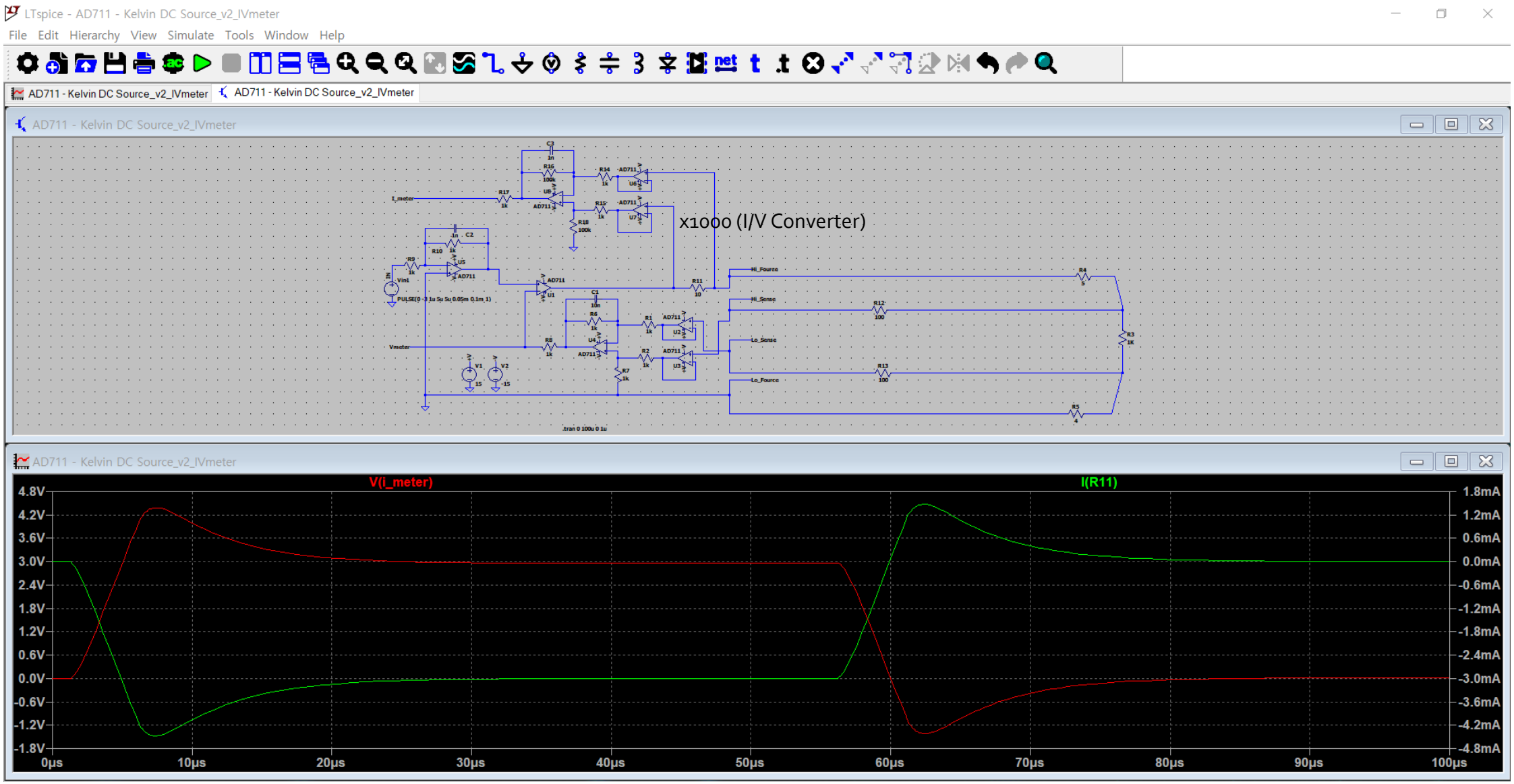
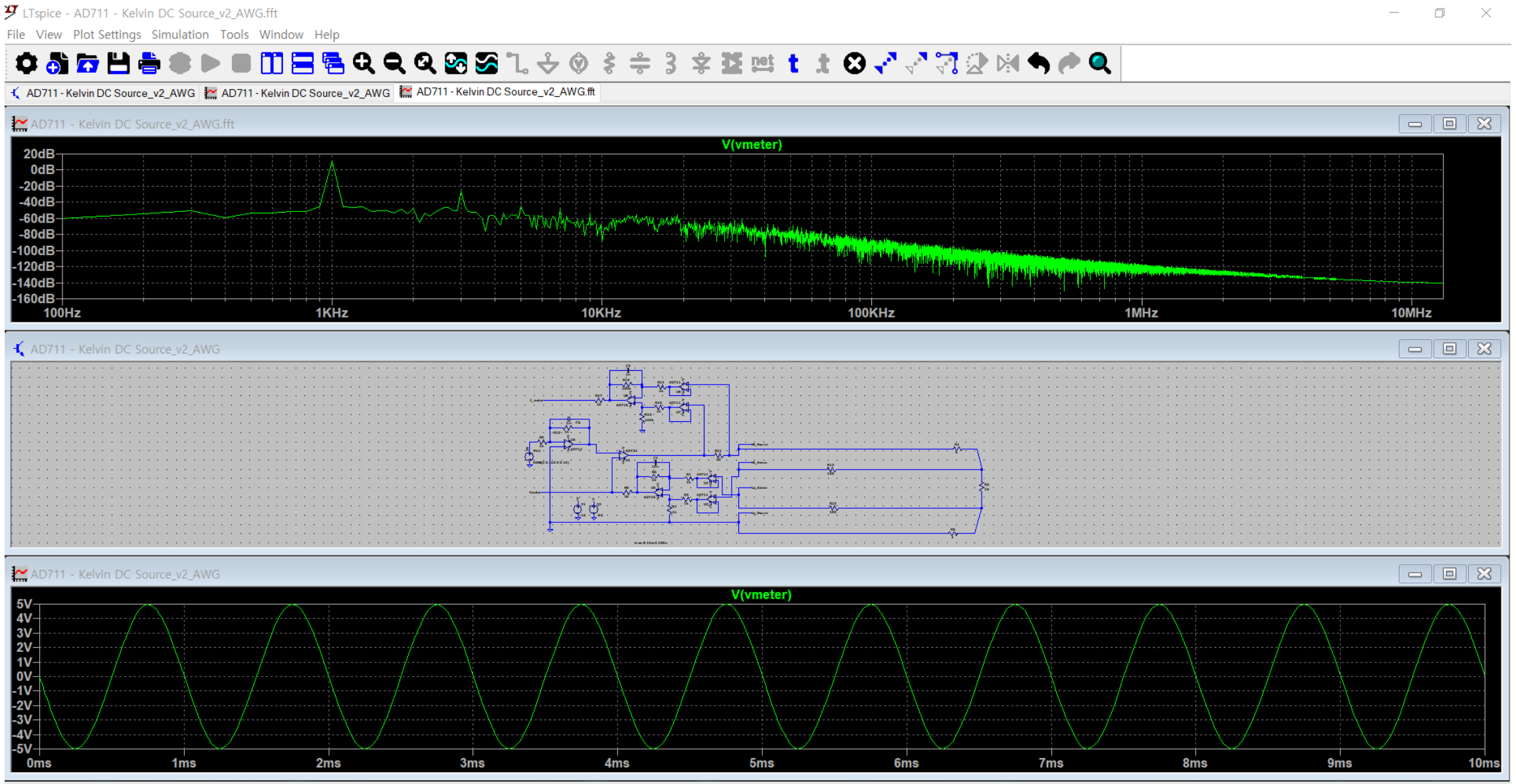
Kelvin Power Supply V/I Meter Circuit



Kelvin Power Supply AWG Mode



DC – Kelvin Connection for Accuracy of Testing

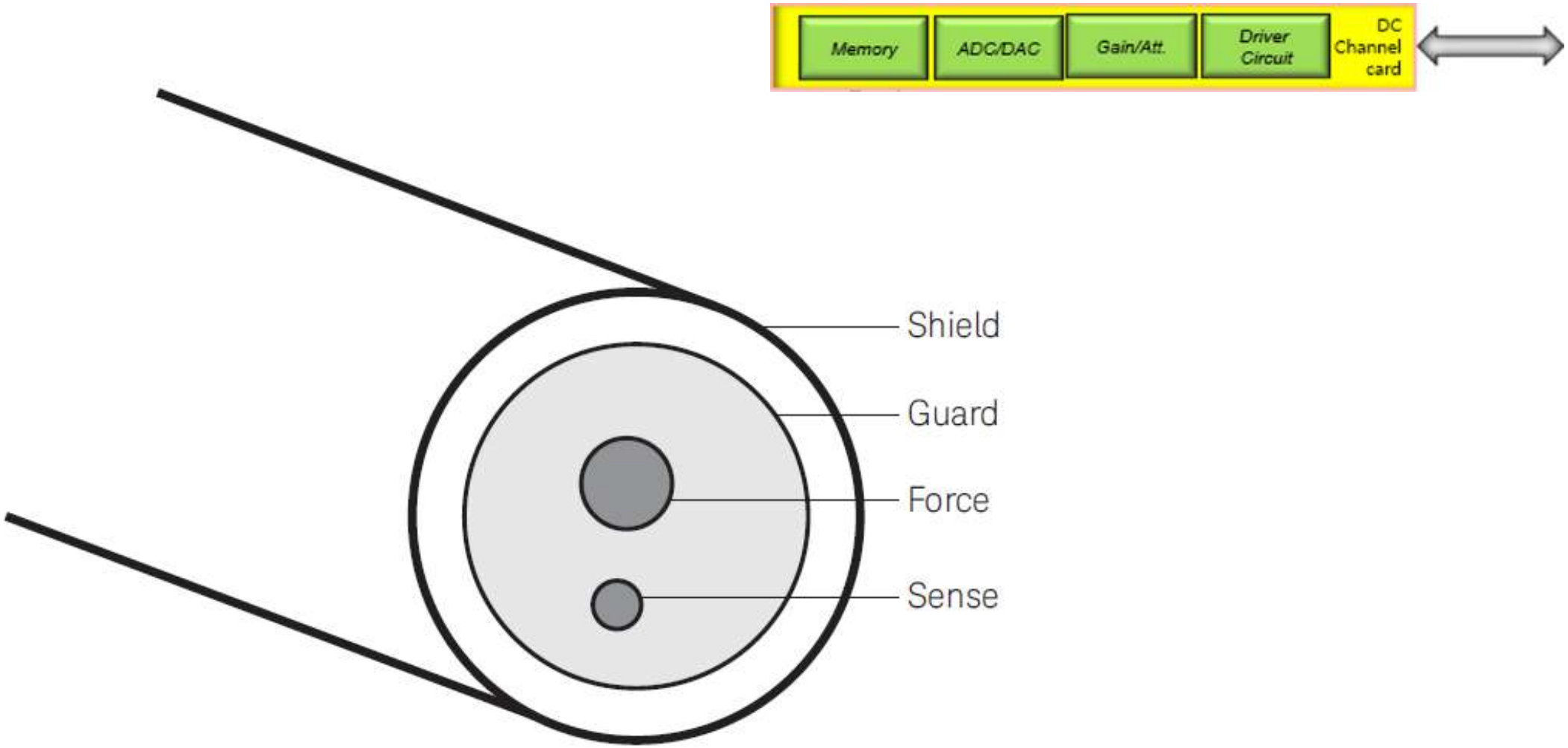
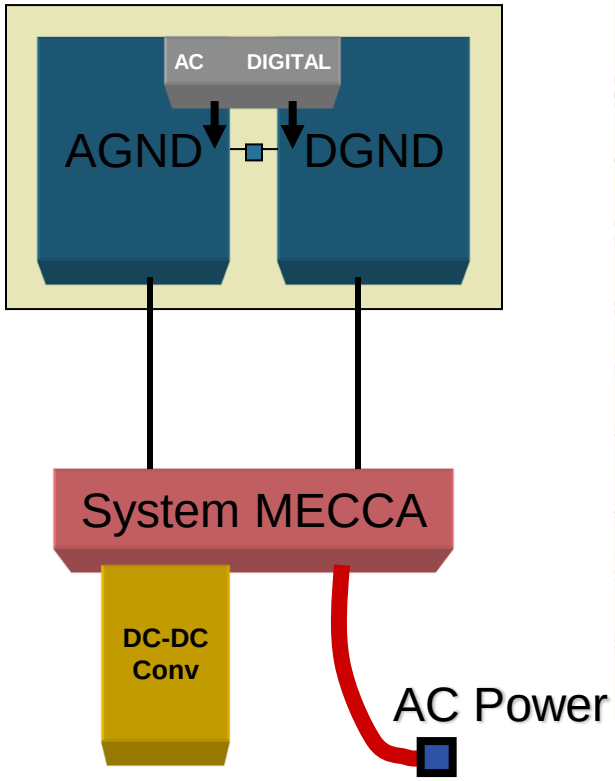
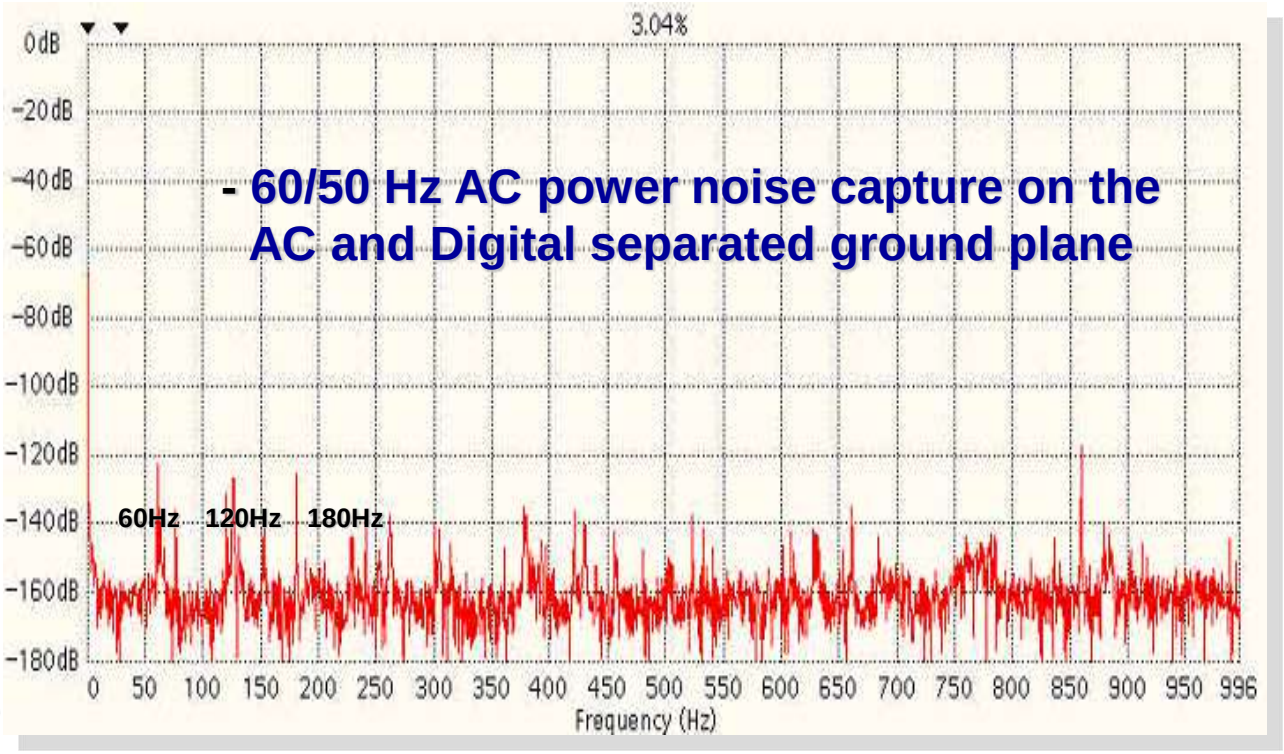


Figure 2.17. The Kelvin triaxial cable combines both the force and sense lines into a single cable.

Ground: Low Noise Ground Plane Design

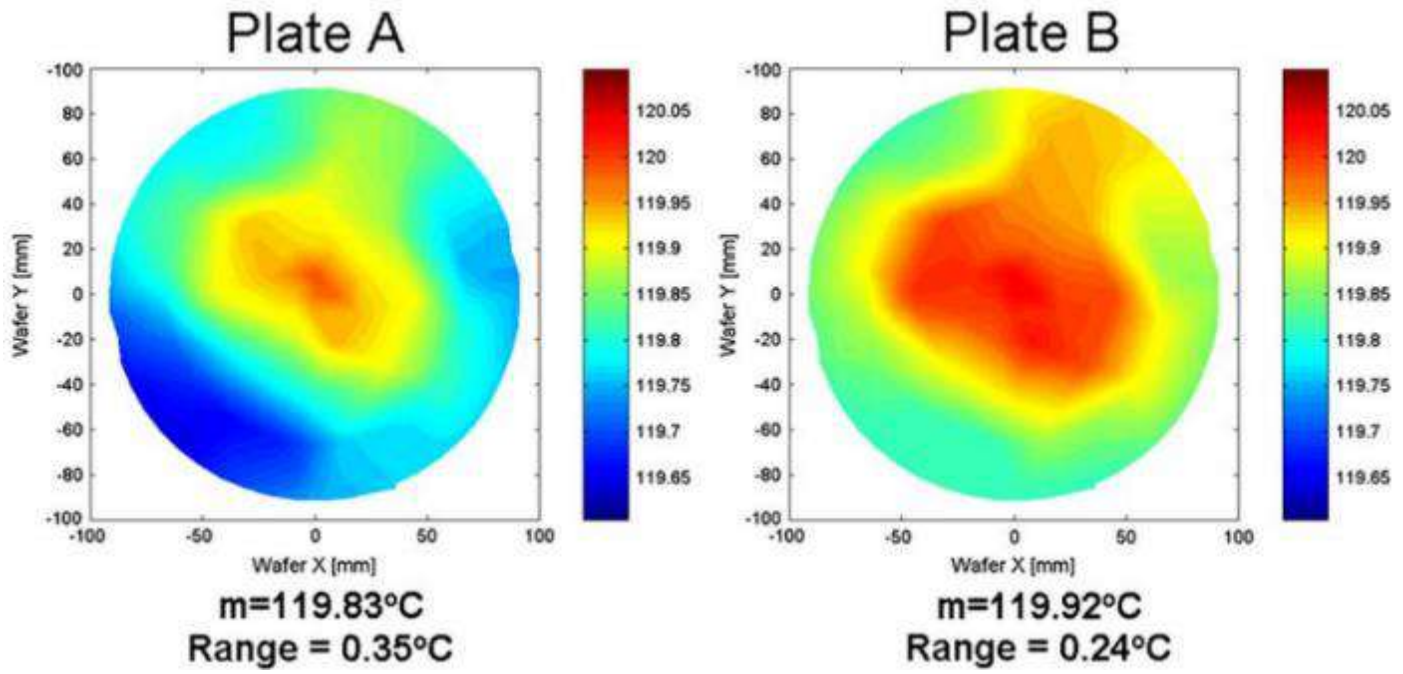
- **Single or Separate Ground plane?**
  - Separated ground plane will capture AC or switching power supply noises
  - Ground noise is directly coupled to converter input and output signal





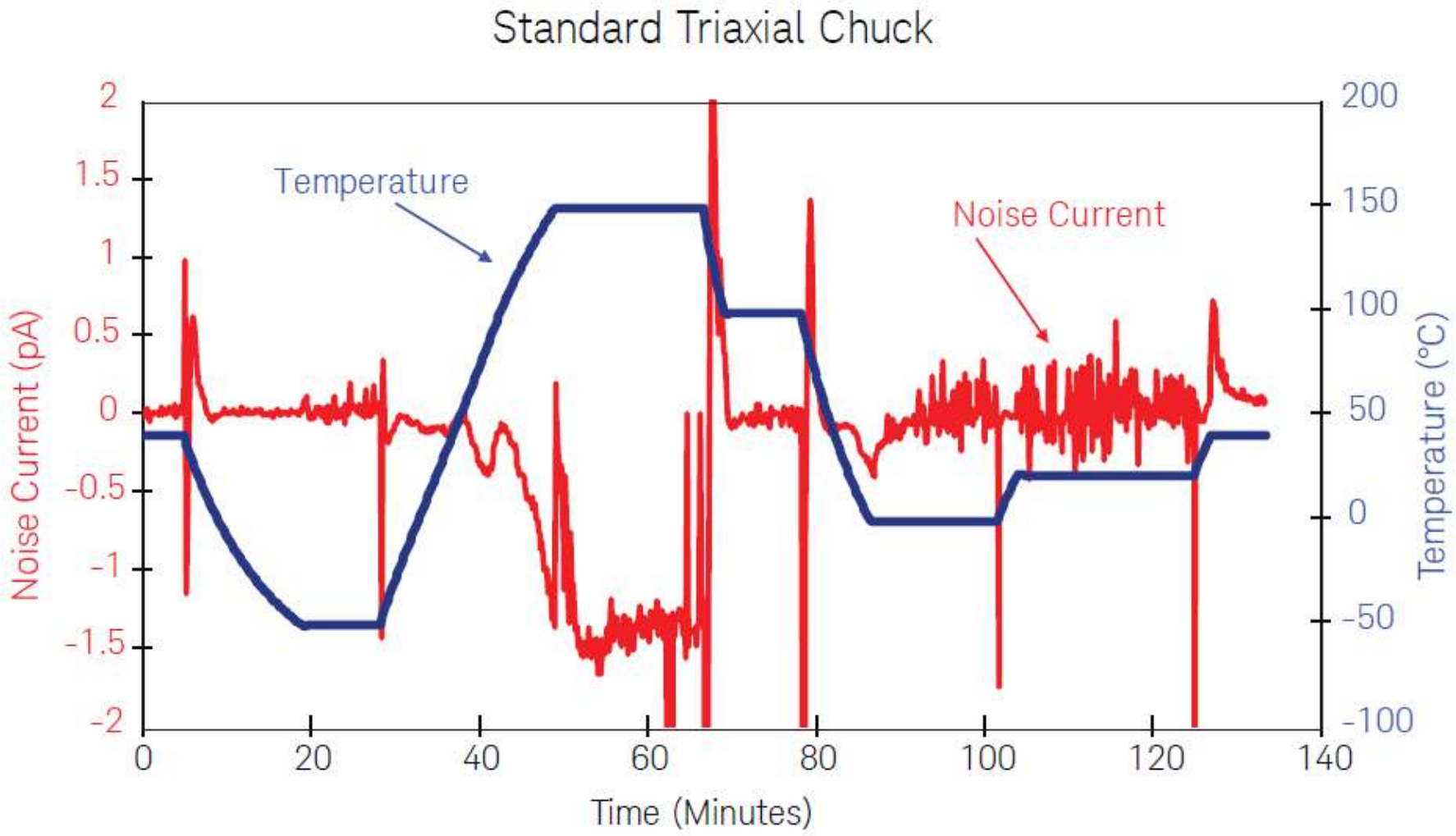
Low and High Temperature Measurement Issues

- **Parametric Measurement Challenge on-wafer at low and high temperatures**
  - *High electrical noise* caused by the thermal control circuitry
  - *Slow measurement times* due to parasitic capacitance
  - *Large transient noise* after wafer chuck moves
  - *Frost* induced moisture leakage



Noise Current for Standard Triaxial Wafer Chuck

As temperature varies over time



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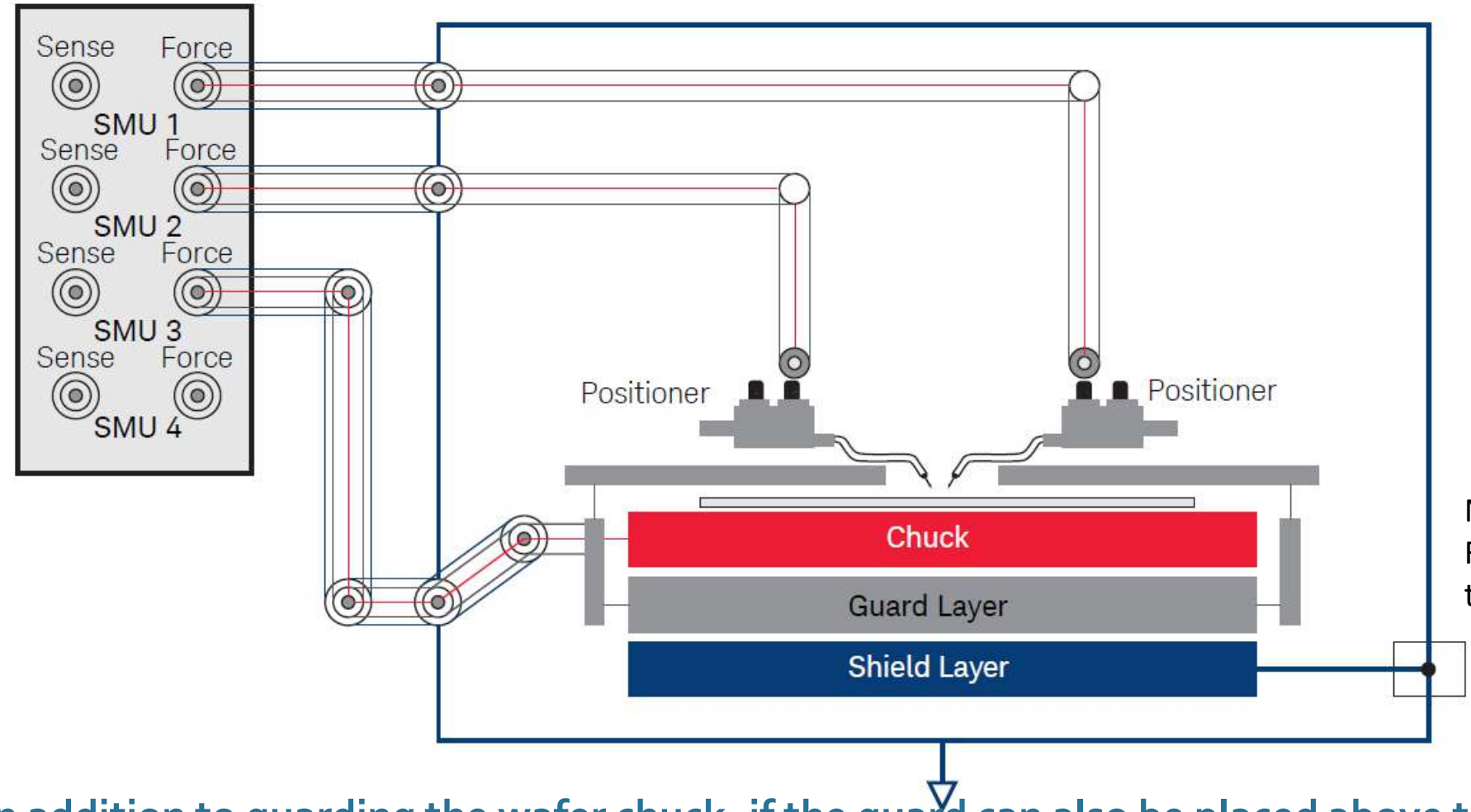
Completely Guarded & Shielded Wafer Probe Environment



Note: Scheme shown is FormFactor's patented AttoGuard technology

In addition to guarding the wafer chuck, if the guard can also be placed above the wafer being measured then noise can be reduced further and an optimal low-noise measurement environment is guaranteed.

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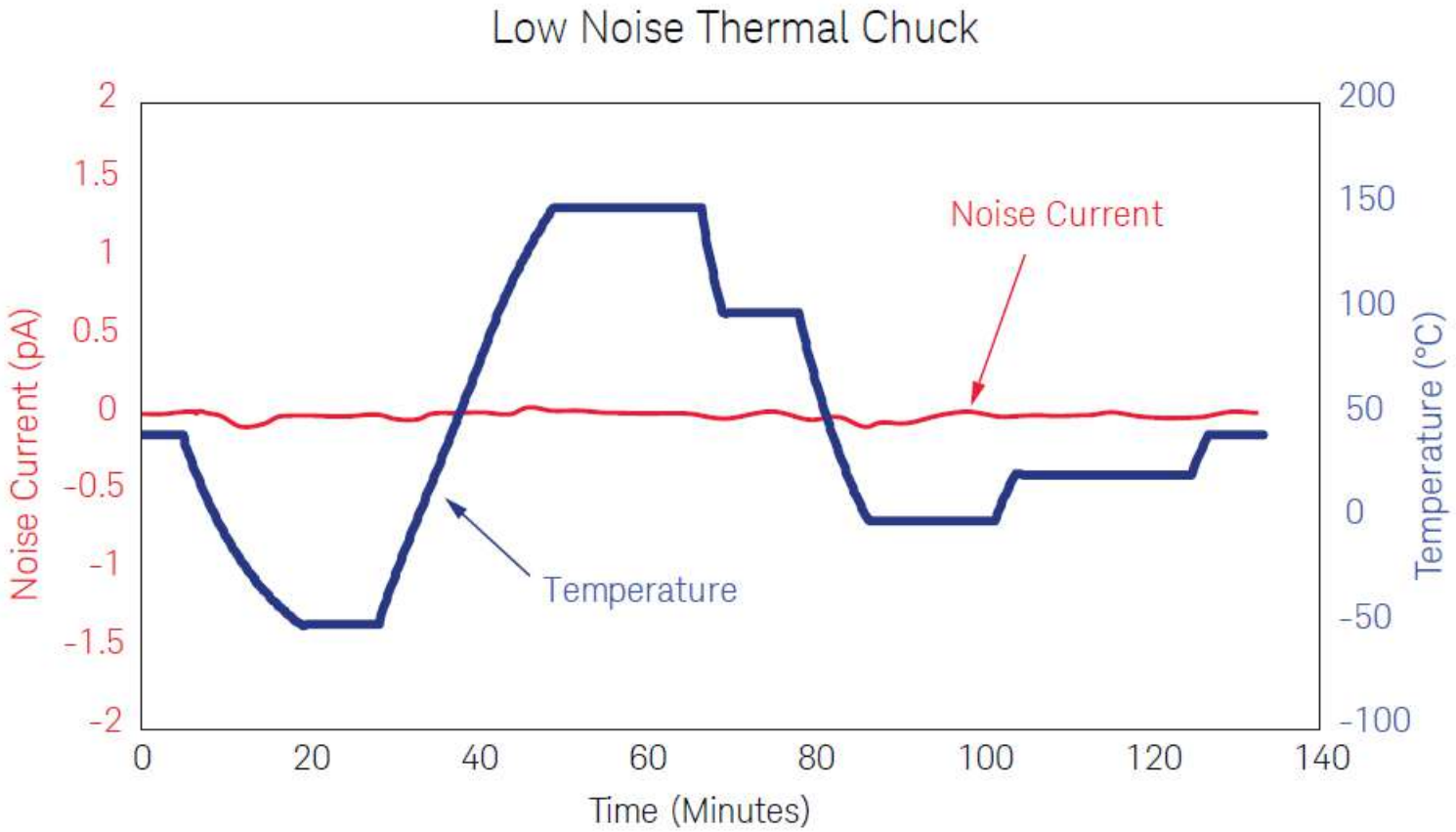
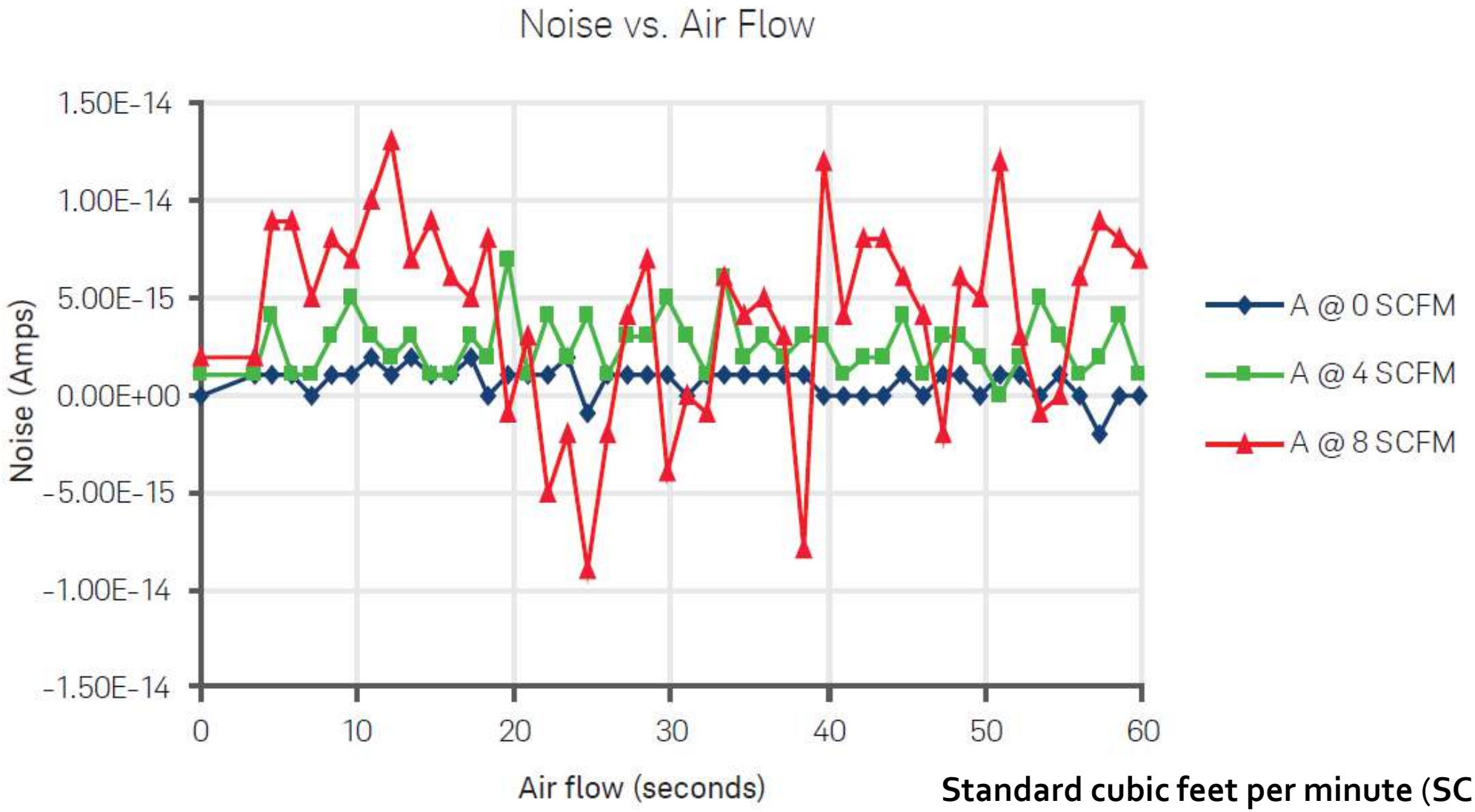
Noise Current

for a Well-designed Low-noise Thermal Wafer Chuck



The Effect of Air Flow on Noise



Standard cubic feet per minute (SCFM)

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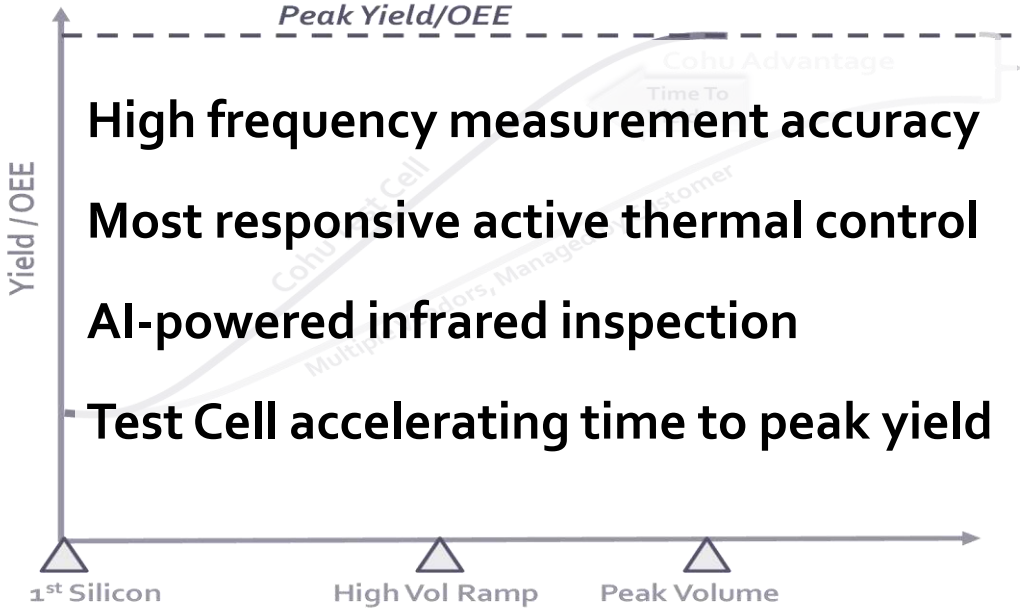
A Unique Combination of All Test Capability

Accelerating ***time to yield*** and ***greater productivity*** through the test cell

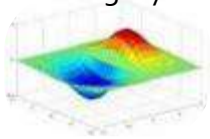
One-stop-shop for leading-edge solutions in test & inspection



- High frequency measurement accuracy
- Most responsive active thermal control
- AI-powered infrared inspection
- Test Cell accelerating time to peak yield

Test Cell Solutions


Test Analytics


Higher Signal Integrity


Active Thermal Control


Efficiency Analytics


Semi Test


Test Contactor


Test Handler

Q&A


"No! I can't be bothered to see any crazy salesmen... we've got a battle to fight!"
Question
SALE

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