Keysight Technologies

Drive Down the Cost of Test Using the ENA Series Vector Network Analyzers

Application Note

KEYSIGHT TECHNOLOGIES

Introduction

The importance of fast, thorough production testing while driving down manufacturing costs continues to be a key driver in a business's ability to compete. Increased product complexity, tightly integrated designs, and the demand for higher manufacturing yields are challenges that must all be addressed. Finding test instruments that can keep pace with these challenges, while providing high reliability, is a critical step in reaching today's increasingly competitive manufacturing goals.

In this application note, we discuss the contributions of Keysight Technologies, Inc.'s ENA Series vector network analyzer to drive down the cost of test in production lines.

Agenda:

- Total cost of ownership (TCO) and Cost of test (COT)
- Value of ENA vector network analyzers
- Conclusion

Total Cost of Ownership (TCO) and Cost of Test (COT)

The product life-cycle of today's new product development has been getting shorter, along with the continuous pressure for product price reduction in the market. The dual challenge of reducing equipment maintenance cost while meeting product quality goals is undeniable, and there is only one way to win: Reduce both the cost of ownership and reduce the cost of test.

Total cost of ownership (TCO)

Total cost of ownership (TCO) is defined to be the total cost to own and operate a piece of equipment over its useful life for testing. There are two core elements in the TCO; capital expenses (acquisition cost) and operating expenses. The following lists the elements, often included in the operating expenses:

- Preventive maintenance costs
- Repair costs
- Downtime mitigation costs (e.g. spare units)
- Technology refresh (e.g. enhancements, upgrades)
- Training & education
- Resale value or disposal cost
- Facilities (e.g. space cost, electricity expense)
- Others (e.g. consumables)

Cost of test (COT)

The cost of test (COT) is defined as the total cost spent for equipment in the testing process in production lines at a specific timing (e.g. test and measurement equipment, automatic component handling machines). COT varies during the useful life of the equipment. Figure 1 illustrates the change of COT from t0 to t3. At the acquiring timing t0, COT consists of capital and initial operating expenses like training and education in addition to other costs (a). At t1, the capital expenses remain as depreciation expenses, but initial operating expenses are removed. After t2, capital expenses are removed, and maintenance expenses are the majority of the COT (b). This maintenance cost will increase at some time when product obtains a discontinued status and the official maintenance service from an equipment supplier ends(c).

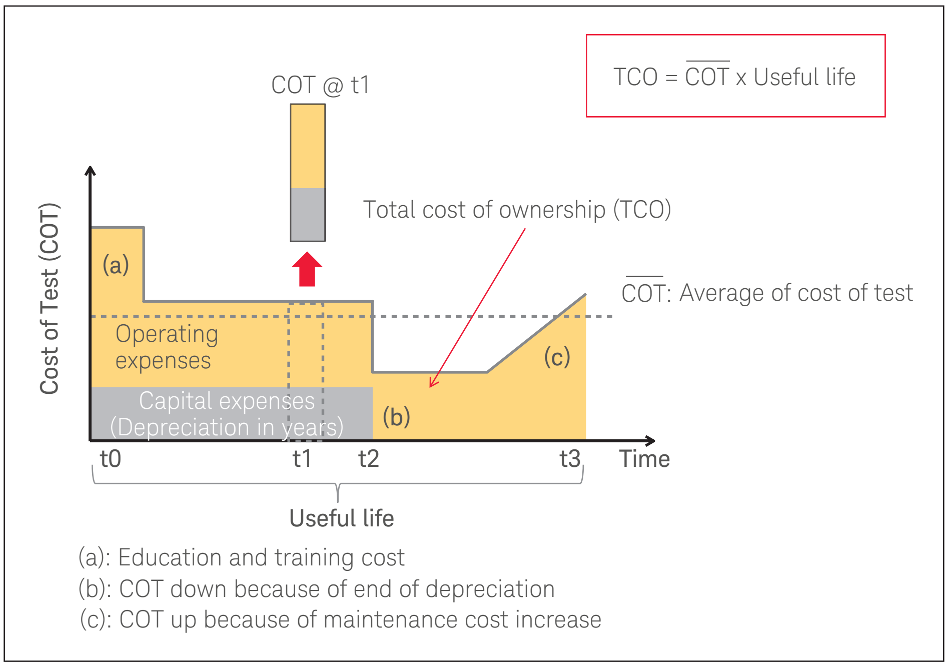


Figure 1. Change in cost of test over time

Here $\overline{\text{COT}}$ is defined as average of COT in its useful life, then TCO can be expressed as

$$\text{TCO} = \overline{\text{COT}} \times \text{Useful life}$$

Thus, COT is the expense required for testing and measuring a device under test (DUT) like equipment, component, and module to specify and assure the performance and quality.

Manufacturing costs continue to decrease as manufacturers strive to meet market prices and remain competitive. Manufacturing costs are now about one-fifth of that in the early 1990s. However, the COT has not changed and is almost the same as it was forty years ago because production line test and measurement requirements have become more complex to test more advanced technology and performance. Companies have gradually cut costs and lead times. It is crucial not to compromise product quality while driving down the cost of test. High-quality products are critical to maintaining the company's competitive edge.

In the total cost of a product, Keysight estimates that cost spent in the production line is about 12% in average. COT occupies one-third of this cost and reaches 4%. Driving down the cost of test is the key factor to winning the business in this very competitive market.

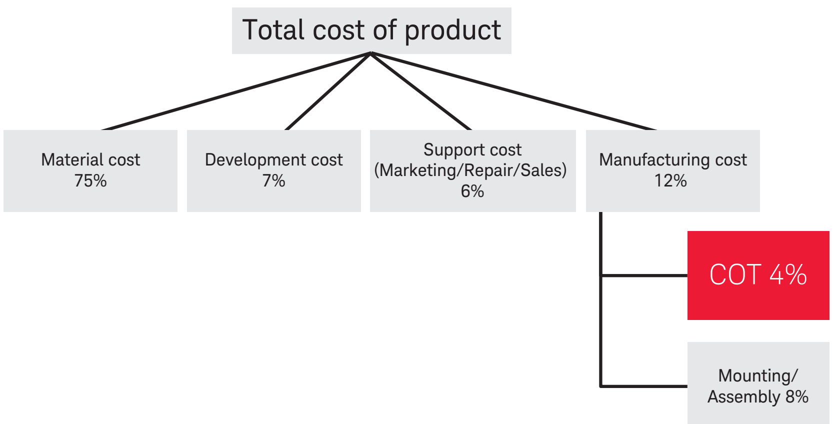


Figure 2. Total cost of product

COT is influenced and varied by the performance and quality of the testing and the measurement equipment used in the production lines. The formula in figure 3 is used to approach the COT by a structured method.

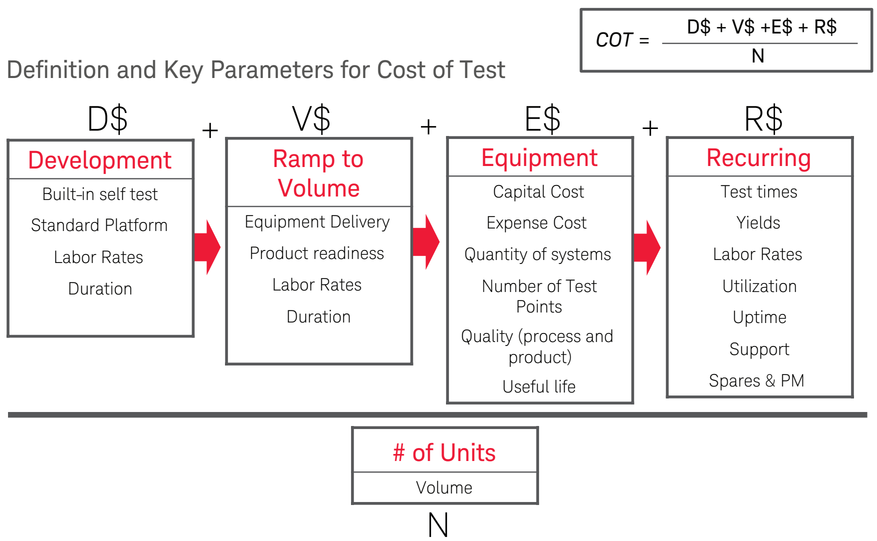


Figure 3. Definition and key parameters for Cost of Test

Development costs (D$) represent the cost to design and develop a test station. It is necessary to determine the software, fixture and necessary equipment for every test point and troubleshoot the process. Additionally, it is also important to consider what documents need to be made, evaluate the quality, design of technician labor rates and system management.

Ramp to volume costs (V$) represent the cost to expand a test station number, including all engineering support for test, verification, mechanical preparation as well as procurement, purchasing, and management costs.

Equipment costs (E$) consist of the purchase price or integration cost for every test point, including troubleshooting costs. Maintenance and scrap cost is also included.

Recurring costs (R$) represent daily operating cost and labor, support labor of engineers and managers, support material cost for spares or equipment failure and preventive maintenance cost.

Finally, the cost is divided by # of units (N). The result is the COT per device under test. Therefore the depreciated capital cost is not the only cost to consider; many factors need to be counted to obtain the total cost of test.

Vector network analyzer in COT

This application note focuses on the contributions vector network analyzers (VNAs) provide to drive down the COT. The table below shows the VNA performance and characteristics that impact the COT.

Table 1: Factors relating to the drive down the cost of test

		Product Attributes										Support Attributes		
Categories	Factors	Price	Speed	Dynamic range	Stability/ accuracy	Small trace noise	Compatibility	User I/F	Upgradeability	Quality/ durability	De-factor Standard	Warranty, repair cost	Support tools/ application expertize	Mfg. capacity/ global company
Development	Built-in self test									✔	✔		✔	
	Standard platform						✔	✔	✔		✔	✔	✔	
	Labor rates						✔	✔			✔		✔	
	Duration													
Ramp to volume	Equipment delivery								✔		✔			✔✔
	Product readines													
	Labor rates						✔							
	Duration													
Equipment	Capital cost	✔✔	✔						✔			✔		
	Expense cost	✔	✔											
	Quantity of systems	✔	✔						✔					
	Number of test points		✔	✔										
	Quality (process and product)				✔						✔		✔	
	Useful life						✔		✔					
Recurring	Test times	✔✔		✔	✔	✔✔		✔					✔	
	Yields			✔	✔✔	✔								
	Labor rates	✔	✔	✔	✔			✔						
	Uptime									✔✔		✔	✔	✔
	Support						✔	✔					✔✔	
	Spares & preventive maintenance	✔	✔				✔						✔	
# of units	Volume		✔	✔	✔	✔								

✔✔ : Heavily related ✔ : Related

The vertical axis shows factors of cost in the COT formula, and horizontal axis shows VNA's performance and product attributes. A single, black checkmark represents that the VNA's attribute is related to a COT factor, and double, red checkmark means that the VNA attribute heavily impacts the COT factor.

Because each VNA has different attributes, every VNA has different contributions to the COT. The next section discusses how the ENA Series specifically contributes to driving down COT.

Value of ENA Series Vector Network Analyzers

Fast speed, small trace noise, and superior stability

When you need to measure S-parameters, the right mix of speed and performance gives you an edge. The Keysight ENA provides affordable measurement integrity to help you transform deeper understanding into a better design. Every Keysight ENA is the ultimate expression of our expertise in linear and nonlinear device characterization.

The ENA has remarkable advantages relating to operating costs, explained in previous section. Add a Keysight ENA to your production line and drive down the cost of test. Overall, the ENA can help you reduce COT.

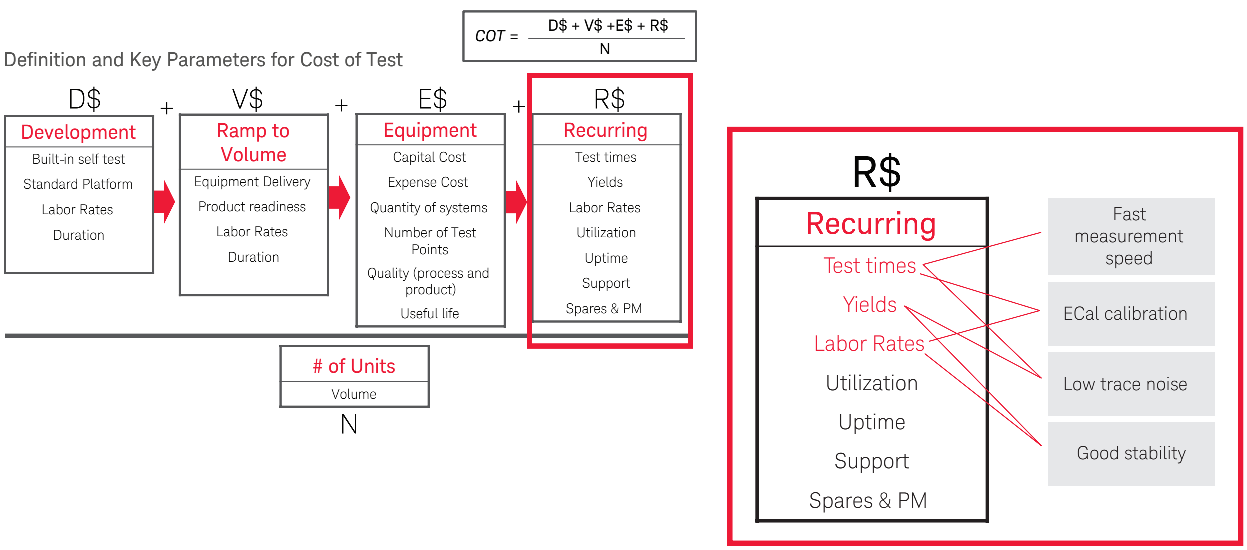


Figure 4. ENA's contributions to drive down the COT

ENA's Contributions to Drive Down the COT

1. Fast measurement speed

The measurement throughput directly impacts the COT. For example, with SAW filter tests used in handset mobile phones, millisecond order measurements are required to produce huge amounts of devices. To achieve this, newer VNAs have a wider IF bandwidth (IFBW), faster CPU performance, and faster error calculation and data processing compared to the legacy VNAs.

The ENA's segment sweep allows you to tailor sweep conditions with arbitrary frequency points, IFBW, the number of measurement points, and more. You can maximize the throughput of your measurements by optimizing setup parameters.

2. Using the ECal module for calibration

Calibration is necessary to get more accurate measurements by eliminating systematic errors resulting from test cables or fixtures in the test setup. The time needed to connect and disconnect calibration standards can be a significant portion of the total calibration process time. To reduce this time, Keysight offers the electronic calibration (ECal) module which is a solid-state device with repeatable impedance states. The ECal module requires only one set of connections to perform a calibration. Therefore it greatly improves your test productivity and minimizes operator's error.

The Keysight N755XA series is an example of the ECal module (Figure 5). This economy 2-port ECal family offers the convenience of an ECal at a significantly lower price point.

Figure 5. N755xA economy Ecal module

3. Low trace noise

Trace noise is one of the important factors that impacts accurate test and test yield. Lower trace noise helps minimize errors and associated test margin when measuring low-loss devices such as filter pass-bands. Because the trace noise increases as the square root of IFBW, you need to select narrower IFBW to obtain lower trace noise.

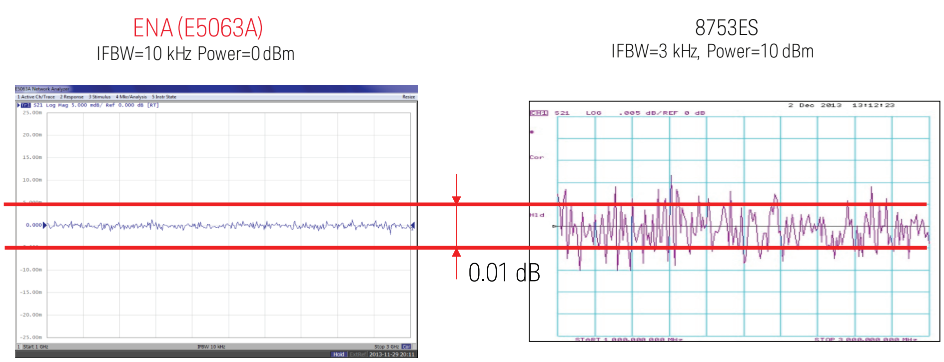


Figure 6. Trace noise comparison (Transmission measurement of thru. 1 to 3 GHz)

The ENA has lower trace noise than other comparable VNAs in the market, so the ENA can use wider IFBW to have the same amount of trace noise; this also makes it possible to improve measurement throughput (Figure 6).

4. Superior measurement stability

Because the VNA's performance is easily affected by the temperature variation in the environment, the measurement stability is one of the key features which represents the design quality of an instrument.

In the production lines, an instrument often runs continuously (24 hours x 7 days) to produce the planned number of production units. However, the environment temperature around the instrument is not stable during the production, so that frequent recalibration is inevitable to eliminate drift errors and achieve the desired level of accuracy.

Also, measurement results with unstable instruments increase measurement uncertainty of go-no-go limit tests, which decreases test yields and increases the COT in production.

Figure 7. Stability comparison. Other VNA may incorrectly fail DUTs overtime due to temperature drift.

The ENA is designed to have the minimum temperature drift against variation of environment temperature, and the typical stability is in the range of 5 to 10 milli-dB per degree C at 3 GHz. This superior measurement stability helps high-volume manufacturers minimize calibration time and associated downtime.

A measurement comparison of a pass band filter shows that the ENA remains more stable compared to the other VNAs a long time after calibration (Figure 7).

5. Reduce ramp to volume - short delivery time on ENA

Short delivery time of the ENA has been recognized as one of the key advantages for manufacturing customers. By centralizing manufacturing facilities and optimizing supply chains, like using common components as much as possible, Keysight has realized and provided the delivery benefit to our customers.

6. Three-year standard warranty

The ENA also offers 3-year standard warranty. Keysight's ability to offer a three-year standard warranty is the result of ongoing quality initiatives that, between 2002 and 2012, yielded unprecedented improvements in product reliability. This combination of reliability and coverage brings you three key benefits: increased confidence in instrument uptime, reduced cost of ownership and greater convenience if service. It's just one more way our solutions help you achieve your business goals. When you choose Keysight, you get greater reliability—standard.

7. Ten-year optional Assurance Plans

Ensure accurate measurements and achieve greater peace of mind with every new instrument purchase.

- Get greater peace of mind — standard — with Keysight's three-year warranty.
- Extend your peace of mind and eliminate budgetary surprises for up to 10 years with Warranty Assurance Plans.
- Lock in OEM-quality calibration at the lowest price, with the peace of mind that your equipment will perform at its original specification with Calibration Assurance Plans.

Assurance Plans are options to your instrument, so it is all part of the same approval process. Warranty Plans are up to 70% less expensive than a comparable per-incident repair; and Calibration Plans are up to 20% less expensive than a single calibration event. Plus, you lock in today's prices to save even more. Both Warranty and Calibration Plans offer a streamlined return process and priority access to our technicians. All Keysight calibrations also include a full inspection and cleaning to help prevent future issues. Longer plans, on-site support, and other options are also available. **www.keysight.com/find/AssurancePlans**

8. Upgradeability

The ENA is a safe investment because of its flexibility. You can easily upgrade the necessary features of the ENA whenever you need the feature. This includes not only software options like time-domain mode or frequency offset mode, but also hardware options such as maximum frequency, number of test ports, and a high stability option.

Conclusion

We discussed the definition of TCO and COT in this application note, and have shown how the vector network analyzer is a key contributor to reducing COT of your production output. The Keysight ENA is a mid-performance vector network analyzer with superior cost performances in the current market. The ENA is designed for use in production lines and has various advantages which help and contribute to drive down the COT at each useful product life cycle. In the initial phase, its superior supportability, functions, information as well as financial program support decreases purchasing and developing costs. In the running test phase, its superior measurement speed, small trace noise, and better stability contributes to reduce the COT drastically. At the end phase, its upgradability and great resale value positively impacts to your company's bottom line and makes it easy to prepare for future test needs. Add the ENA to your line—and drive down the cost of test.

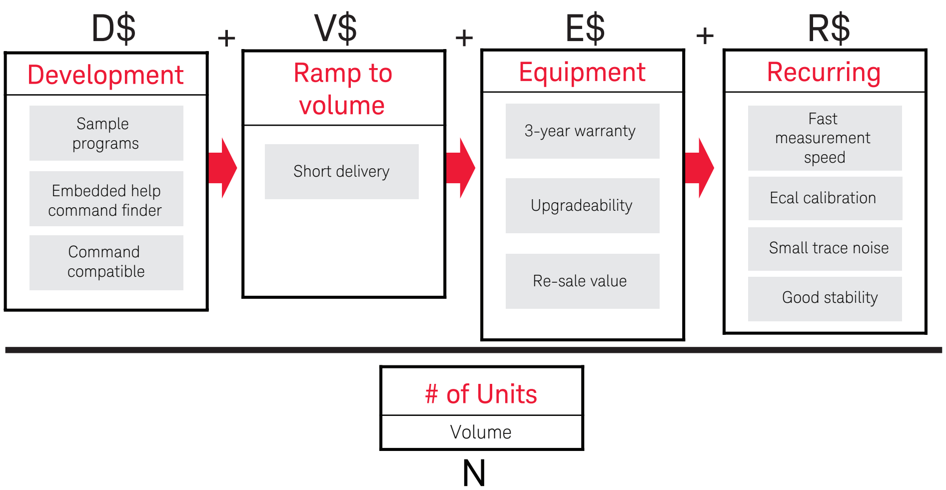


Figure 9. The ENA contribution to drive down the cost of test

References and Links

Keysight ENA Series Vector Network Analyzer Web Page
www.keysight.com/find/vna

White Paper: The Real "Total Cost of Ownership of Your Test Equipment, literature number 5990-6642EN
http://literature.cdn.keysight.com/litweb/pdf/5990-6642EN.pdf

Managing Your Test Equipment's Total Cost of Ownership, literature number 5990-9133EN
http://literature.cdn.keysight.com/litweb/pdf/5990-9133EN.pdf

Appendix

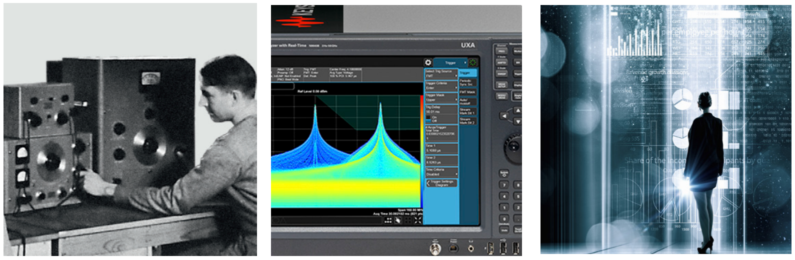
Comparison of Keysight's bench-top RF VNAs (as of June 2017)

	E5080A	E5071C	E5072A	E5061B (RF NA options)	E5063A	8753ES (obsolete)
Frequency	9 k to 4.5/6.5/9 GHz	9/100 k to 4.5/6.5/8.5 GHz, 300 k to 14/20 GHz	30 k to 4.5/8.5 GHz	100 k to 1.5/3 GHz	100 k to 0.5/3/4.5/6/8.5/14/18 GHz	30 k to 3/6 GHz
Test port	2 & 4-port, 50 Ω	2 & 4-port, 50 Ω	2-port, 50 Ω	2-port, 50 & 75 Ω	2-port, 50 Ω	2-port, 50 & 75 Ω
Dynamic range (@ 3GHz)	135 dB (spec) 147 dB (typ.)	123 dB (spec) 130 dB (typ.)	123 dB (spec) 130 dB (typ.)	120 dB (spec) 130 dB (typ.)	117 dB (spec) 122 dB (typ.)	110 dB (spec)
Trace noise (@ 3 GHz)	0.0015 dBrms (IFBW=10 kHz)	0.003 dBrms (IFBW=70 kHz)	0.004 dBrms (IFBW=70 kHz)	0.005 dBrms (IFBW=3 kHz)	0.005 dBrms (IFBW=70 kHz)	0.006 dBrms (IFBW=3 kHz)
Stability (@ 3 GHz)	0.005 dB/° C	0.005 dB/° C	0.005 dB/° C	0.01 dB/° C	0.01 dB/° C	0.02 dB/° C
Source power (@ 3 GHz)	–90 to +15 dBm	–55 to +10 dBm	–85 to +16 dBm	–45 to +10 dBm	–20 to 0 dBm	–85 to +10 dBm
Sweep type	Lin/Log freq, Segment, Power sweep	Lin/Log freq, Segment, Power sweep	Lin/Log freq, Segment, Power sweep	Liner/Log freq, Segment, Power sweep	Liner/Log freq, Segment	Lin/Log freq, Segment, Power sweep
Cycle time (2-port cal, NOP=201)	3 ms (IFBW=500 kHz)	5 ms (IFBW=500 kHz)	4 ms (IFBW=500 kHz)	21 ms (IFBW=300 kHz)	19 ms (IFBW=300 kHz)	139 ms (IFBW=6 kHz)
NOP	Max. 100,001	Max. 20,001	Max. 20,001	Max. 1,601	Max. 10,001	Max. 1,601
Channel	Max. 200	Max. 160	Max. 160	Max. 4	Max. 32	Max. 2
Bias tees	Yes	Yes[1]	Yes	No	No	Yes
Configurable test set	No	No	Yes	No	No	Yes[1]
Freq. offset mode	Yes[1]	Yes[1]	Yes[1]	No	No	Yes[1]
Time domain analysis	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]
Fixture simulator	Yes	Yes	Yes	No	Yes	No
Limit test	Limit line, Ripple limit, Bandwidth limit, Point limit	Limit line, Ripple limit, Bandwidth limit, Point limit	Limit line, Ripple limit, Bandwidth limit	Limit line, Ripple limit, Bandwidth limit	Limit line, Ripple limit, Bandwidth limit, Point limit	Limit line, Ripple limit, Bandwidth limit, Point limit
Source/receiver power cal	Yes	Yes	Yes	No	No	Yes
8753 code translator	Yes	Yes	Yes	No	No	
Other major capabilities	High-stability oven[1], DC inputs, Equation editor, Smart cal wizard, PMAR	High-stability oven[1], DC inputs, Probe power, Equation editor, Enhanced TDR[1]	High-stability oven[1], DC inputs, Probe power, Equation editor	High-stability oven[1], SRL analysis[1], Equation editor	Test Wizard[1], Equation editor	High-stability oven[1], DC inputs, Probe power
User interface	Touch-based GUI (Tabbed soft panel & dialogs/wizards)	Touch-based soft key tree UI	Touch-based soft key tree UI	Touch-based soft key tree UI	Touch-based soft key tree UI	Soft key tree UI

1. Optional capability

Evolving

Our unique combination of hardware, software, support, and people can help you reach your next breakthrough. We are unlocking the future of technology.



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Published in USA, July 5, 2017
5992-0195EN
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