APPLICATION NOTE

# Drive Down the Cost of Test

## Using E5080B ENA Series Vector Network Analyzer

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's E5080B 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 E5080B ENA
- 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).

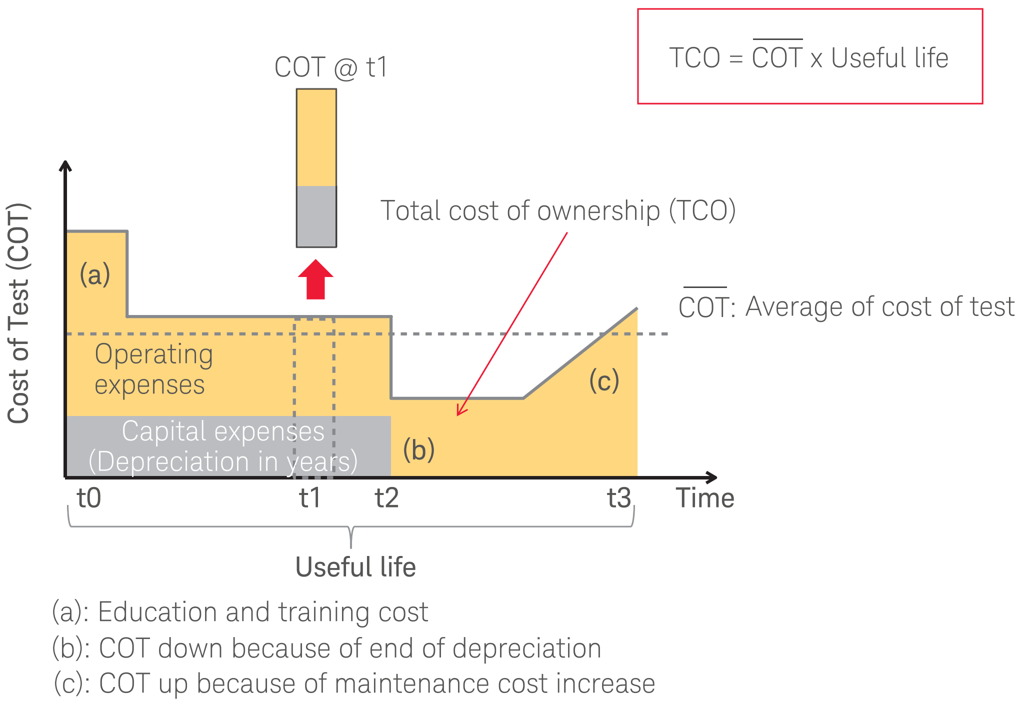


Figure 1. Change in cost of test over time

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

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

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.

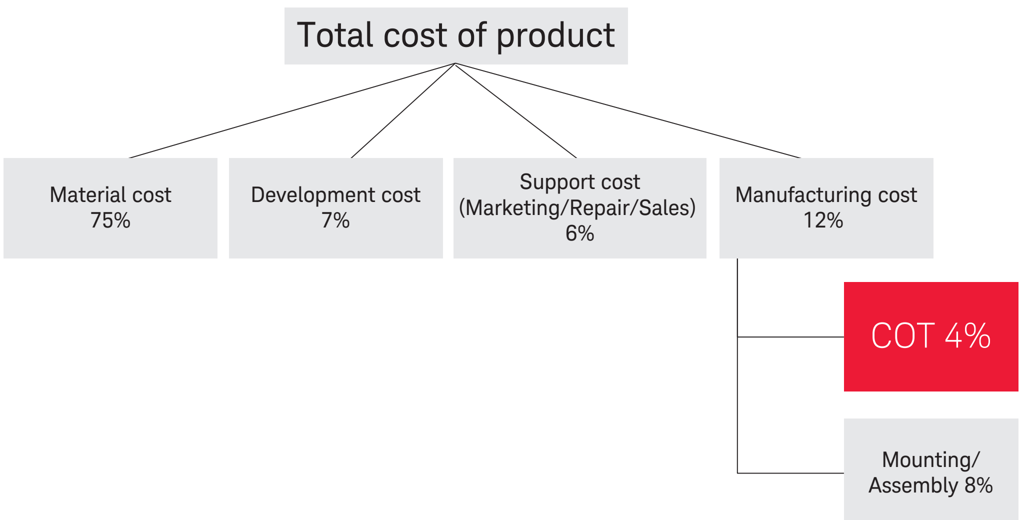


Figure 2. Total cost of product

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.

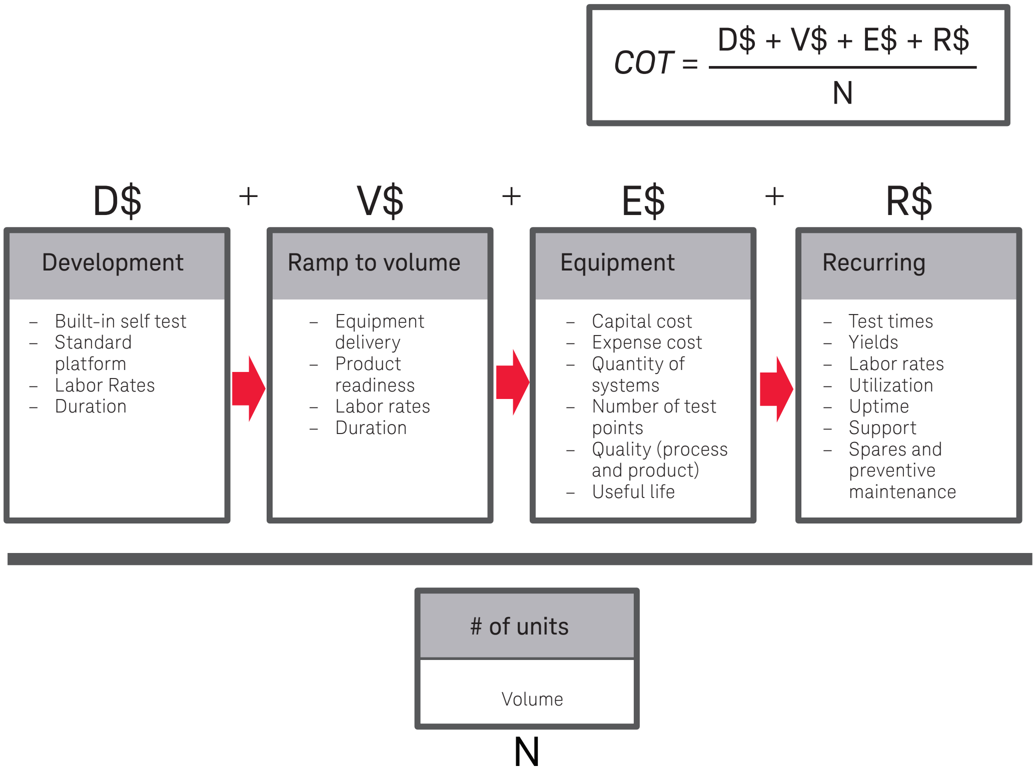


Figure 3. Definition and key parameters for Cost of Test

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

| Categories of costs | Factors | Price | Built-in hardware capability | Integrated application software | Speed | Dynamic range | Temperature stability | Trace noise/ accuracy | Compatibility | User interface | Upgradability | Quality/ durability | De-facto standard | Warranty, repair cost | Application expertize | Mfg. capacity/ global support |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Development costs (D$) | Built-in self test | √ | | | | | | | | | | √ | √ | | √ | |
| | Standard platform | | √ | √ | | | | | √ | √ | √ | | √ | √ | √ | |
| | Labor rates | | √ | √ | | | | | √ | √ | | | √ | | √ | |
| | Duration | | | | | | | | | | | | | | | |
| Ramp to volume costs (V$) | Equipment delivery | | | | | | | | | | √ | | √ | | | √√ |
| | Product readiness | | | √ | | | | | | | | | | | | |
| | Labor rates | | √ | √ | | | | | √ | | | | | | | |
| | Duration | | | | | | | | | | | | | | | |
| Equipment costs (E$) | Capital cost | √√ | | | | | | | | | √ | | | √ | | |
| | Expense cost | √ | | | | | | | | | | | | | | |
| | Quantity of systems | √ | | | | | | | | | | | | | | |
| | Number of test points | | √ | | √ | | | | | | | | | | | |
| | Quality (process and product) | | | | | | √ | √ | | | | | √ | | √ | |
| Recurring costs (R$) | Test times | | √ | √ | √√ | √ | | √√ | | √ | | | | | √ | |
| | Yields | | | | | √ | √√ | √ | | | | | | | | |
| | Labor rates | | | √ | | | | | √ | √ | | | | | | |
| | Uptime | | | | | | | | | | | √√ | | √ | √ | √ |
| | Support | | | | | | | | √ | √ | | | | | √√ | |
| | Spares and preventive maintenance | √ | √ | √ | | | | | √ | √ | | | | | √ | |
| Number 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.

# Values of E5080B ENA Series Vector Network Analyzer

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 enhances your expertise in linear and nonlinear device characterization.

The ENA has remarkable advantages relating to operating costs, explained in the 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.

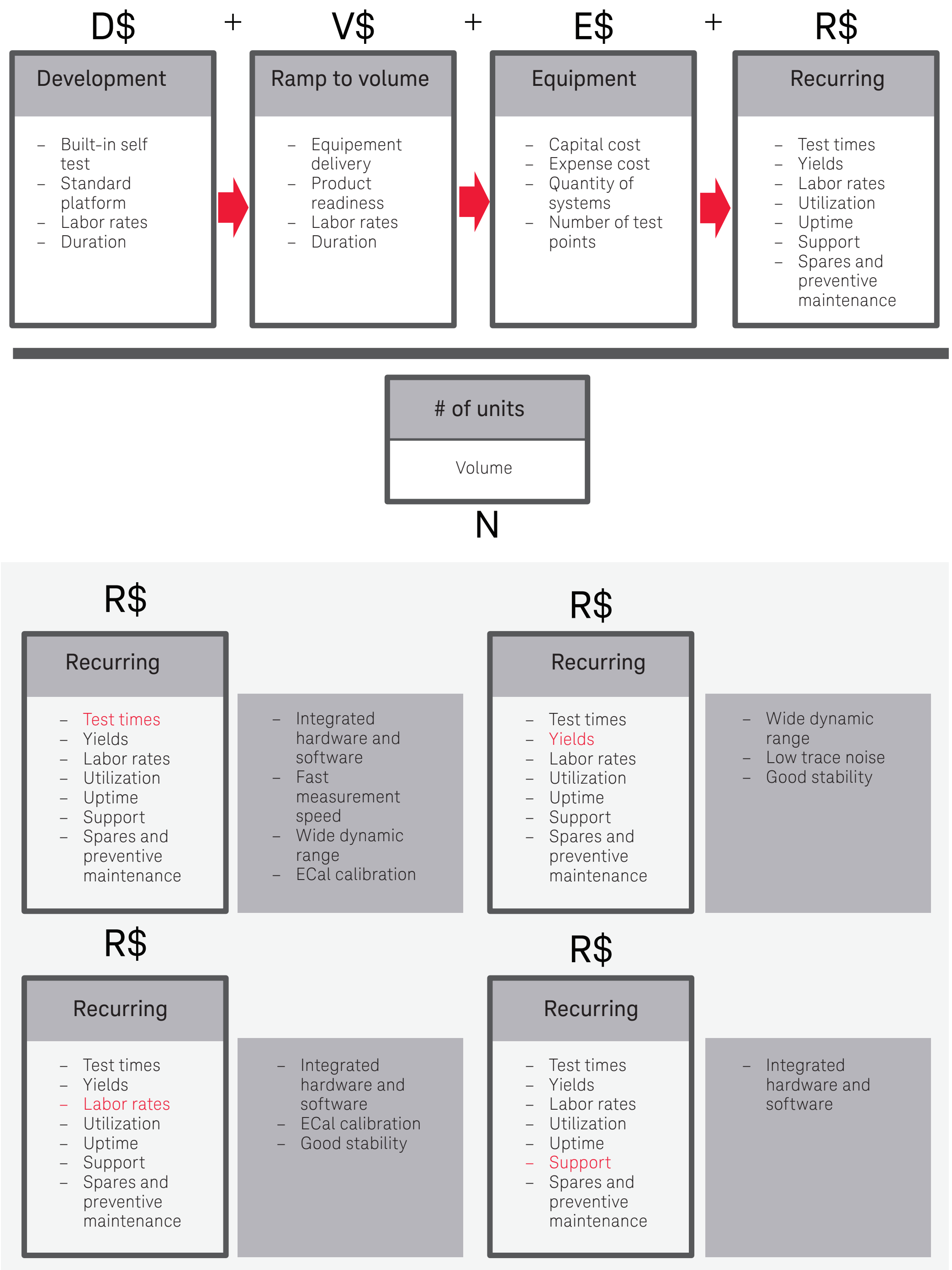


Figure 4. ENA's contributions to drive down the COT

# Simplified Faster Measurement Setup with Built-in Hardware and Software

The E5080B integrates built-in capabilities including internal DC sources, DC monitor inputs, spectrum analysis, pulse generators or pulse modulators. While the traditional test setup requires multiple instruments such as a DC power supply, digital multimeter, spectrum analyzer, or pulse generators, the E5080B eliminates the cost associated with additional instruments.

Integrated application software for the E5080B reduces the engineer's workload and time needed for the development of the program for automated measurements with multiple instruments. R&D engineers benefit from the intuitive GUI to start measurements quickly.

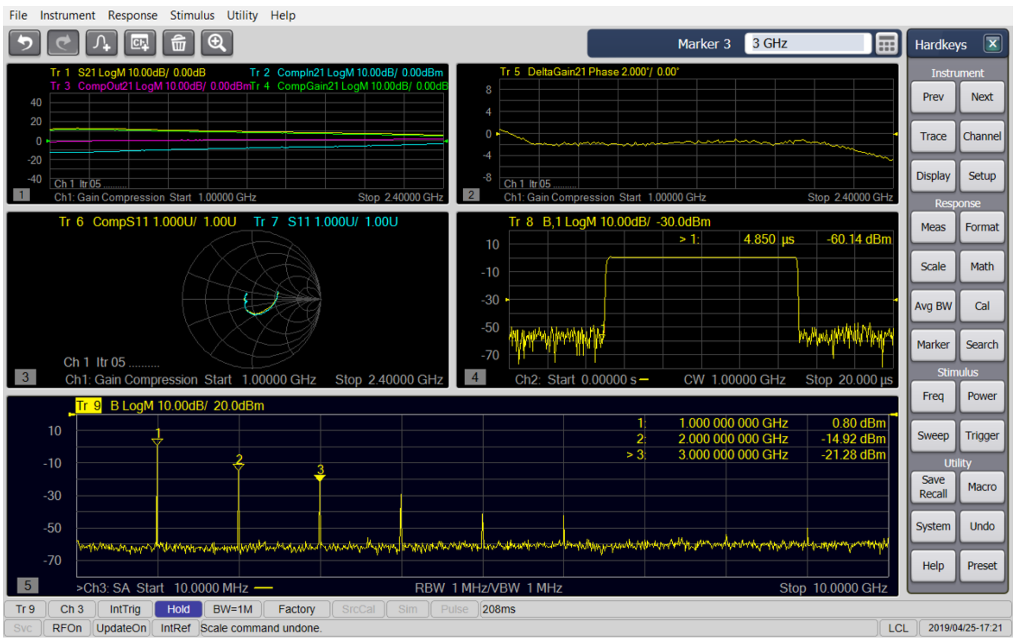


Figure 5. The E5080B's network analysis and spectrum analysis capabilities with a single instrument

# Fast Measurement Speed

Measurement throughput directly impacts the COT. For example, with SAW filter tests used in handset mobile phones, millisecond-order measurements are required to produce vast amounts of devices. To achieve this, the E5080B has a wide IF bandwidth (IFBW) for faster measurement sweeps, faster error calculation and data processing compared to the other VNAs. The E5080B completes the same measurement more than four times faster than the E5071C (Figure 6).

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.

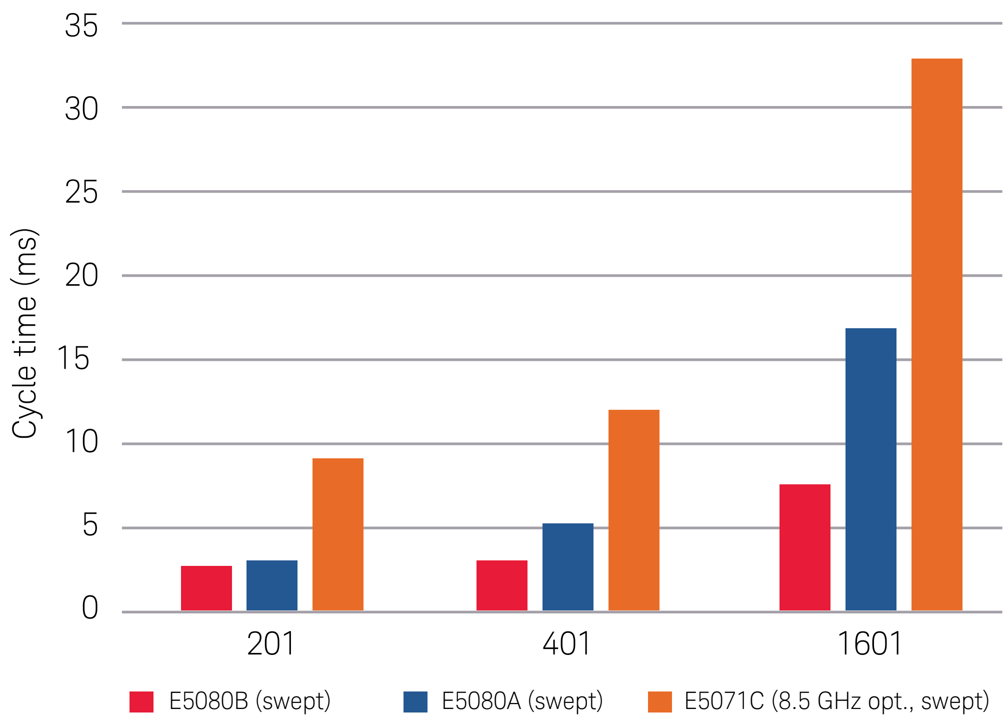


Figure 6. Cycle time comparison of the ENA series with swept (fast sweep) mode. Full 2-port calibrated measurement for 0.8 to 1 GHz with 201, 401 and 1,601 points.

## Optimizing Test Throughout with Wide Dynamic Range

Achieving the widest possible dynamic range with the VNA is critical when characterizing many types of RF devices such as high-rejection filters for wireless communication applications.

The wide dynamic range improves throughput of measurements of high-attenuating devices, because a wider IFBW can be selected to achieve the result. If dynamic range is increased by 20 dB then 100-times wider IFBW can be selected, thus 100-times faster measurements can be performed to get the same result. The E5080B's specified dynamic range of 140 dB enables quick and accurate filter measurements.

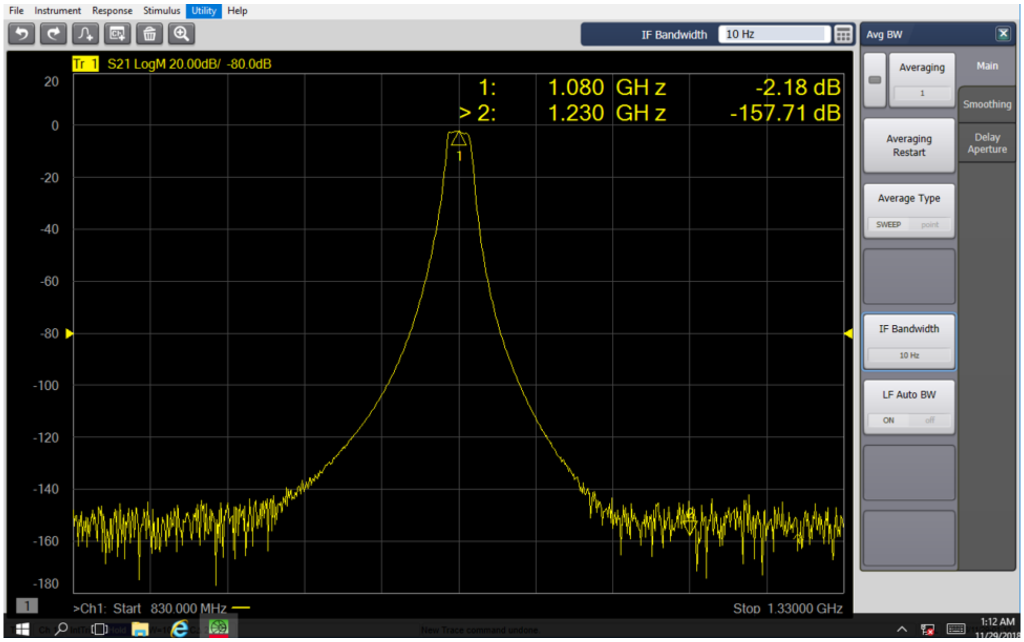


Figure 7. The E5080B's best-in-class dynamic range for optimizing test throughput

## Quick Calibration Using the ECal Module

Calibration eliminates systematic errors resulting from test cables or fixtures in the test setup, providing accurate measurements. 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, a solid-state device with repeatable impedance states. The ECal module requires only one set of connections to perform a calibration, significantly improving your test productivity and reducing operator error.

Keysight offers a wide range of ECal modules – you may select from minimum and maximum frequency, number of ports, number of connector types, and performance versus economy ECal modules.

Figure 8. Precision N469xD Series ECal modules assists quick and accurate calibration from DC up to 67 GHz

# Improving Yield with Low Trace Noise

Trace noise is a key factor impacting accurate test and test yield. Lower trace noise helps minimize errors and associated test margin when measuring low-loss devices such as cable assemblies or 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.

The ENA has lower trace noise than other comparable VNAs in the market, so the ENA can use a wider IFBW with the same amount of trace noise. The wider IFBW improves measurement throughput.

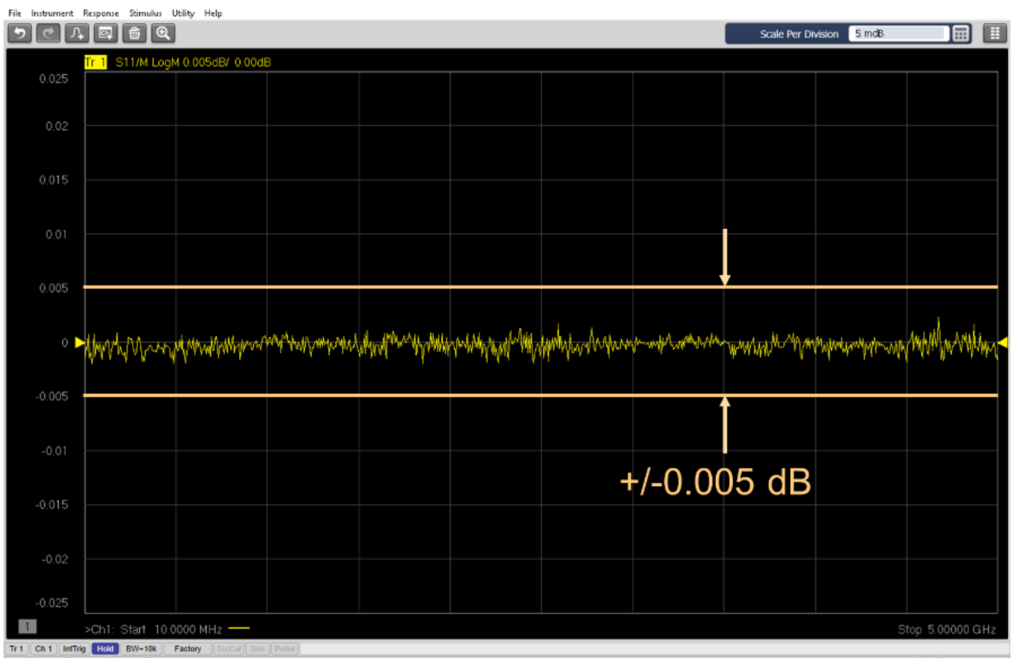


Figure 9. Low trace noise minimizes test margin to improve yield of your products

## More Stable Measurements

Because the VNA's performance is easily affected by temperature variation in the environment, measurement stability is one of the key indicators of design quality of an instrument. In production lines, an instrument often runs continuously (24 hours x 7 days) to meet production goals. However, the environment temperature around the instrument changes over time, so frequent recalibration is required 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.

The ENA is designed to minimize 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.

# 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.

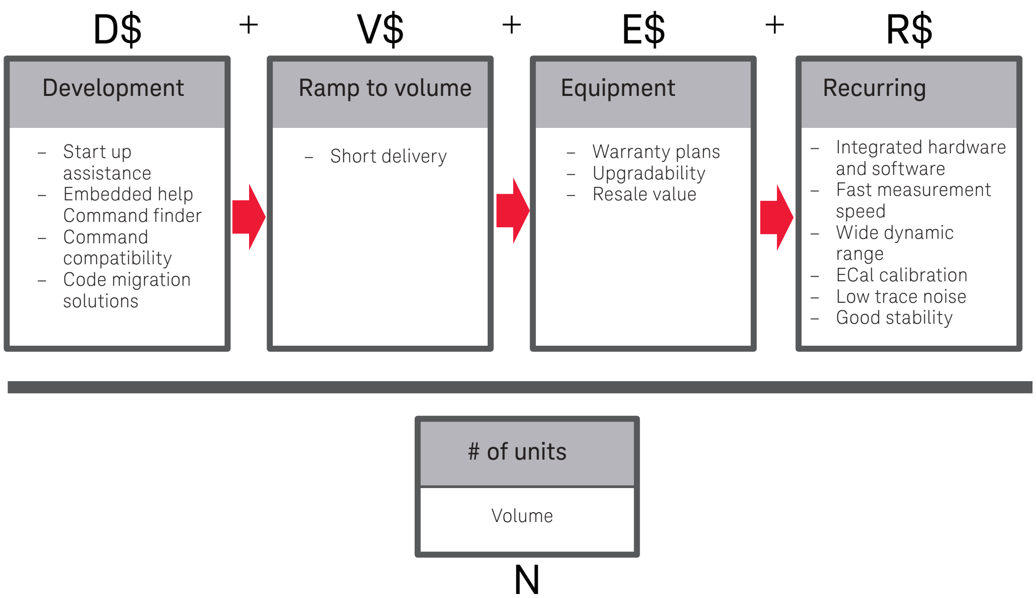


Figure 10. The ENA contribution to drive down the cost of test

# Appendix

Comparison of Keysight's ENA Series VNAs.

| | **E5063A** | **E5061B (RF NA options)** | **E5071C** | **E5072A** | **E5080A** | **E5080B** |
|---|---|---|---|---|---|---|
| Min frequency | 100 kHz | 100 kHz | 9/100 kHz, 300 kHz | 30 kHz | 9 kHz | 9 kHz |
| Max frequency | 0.5/3/4.5/6/8.5/14/18 GHz | 1.5/3 GHz | 4.5/6.5/8.5 GHz 14/20 GHz | 4.5/8.5 GHz | 4.5/6.5/9 GHz | 4.5/6.5/9/14/20 GHz |
| Test port | 2-port, 50 Ω | 2-port, 50 and 75 Ω | 2 and 4-port, 50 Ω | 2-port, 50 Ω | 2 and 4-port, 50 Ω | 2 and 4-port, 50 Ω |
| Dynamic range (at 3 GHz) | 117 dB | 120 dB | 123 dB | 123 dB | 135 dB | 140 dB |
| Trace noise (at 3 GHz) | 0.005 dBrms (70 kHz IFBW) | 0.005 dBrms (3 kHz IFBW) | 0.003 dBrms (70 kHz IFBW) | 0.004 dBrms (70 kHz IFBW) | 0.0015 dBrms (10 kHz IFBW) | 0.0015 dBrms (10 kHz IFBW) |
| Source power (at 3 GHz) | –20 to 0 dBm | –45 to 10 dBm | –55 to 10 dBm | –85 to 16 dBm | –90 to 15 dBm | –60 to 10 dBm |
| Temperature stability (at 3 GHz, typ) | 0.01 dB/deg.C | 0.01 dB/deg.C | 0.005 dB/deg.C | 0.005 dB/deg.C | 0.005 dB/deg.C | 0.005 dB/deg.C |
| Cycle time (2-port cal, 201 points. typ) | 19 ms (300 kHz IFBW) | 21 ms (300 kHz IFBW) | 5 ms (100 kHz IFBW) | 4 ms (500 kHz IFBW) | 3 ms (500 kHz IFBW) | 2 ms (1 MHz IFBW) |
| IF bandwidth (IFBW) | 10 Hz to 300 kHz | 1 Hz to 300 kHz | 10 Hz to 1.5 MHz | 10 Hz to 500 kHz | 1 Hz to 1.5 MHz | 1 Hz to 15 MHz |
| Internal bias tees | No | No | Yes | Yes | Yes | Yes |
| Configurable test set | No | No | No | Yes | No | No |
| Multiport test set support | No | No | Yes | No | Yes | Yes |
| Internal pulse modulators | No | No | No | No | No | Yes |
| Internal pulse generators | No | No | No | No | No | Yes |
| Internal DC sources | No | No | No | No | No | Yes |
| DC monitor (AUX Input) ports | No | No | Yes | Yes | Yes | Yes |
| Spectrum analysis hardware | No | No | No | No | No | Yes |
| Key software capability | Time domain analysis, PCB impedance analysis, wireless power transfer analysis | Time domain analysis, wireless power transfer analysis | Time domain analysis, frequency offset mode, scalar mixer measurement | Time domain analysis, frequency offset mode, scalar mixer measurement, wireless power transfer analysis | Automatic fixture removal, time domain analysis, gain compression application, frequency offset mode, scalar mixer measurement, automated measurement expert | Automatic fixture removal, time domain analysis, enhanced time domain analysis with TDR, gain compression application, pulse measurement, frequency offset mode, scalar mixer measurement, embedded LO, spectrum analysis, automated measurement expert |
| User interface | ENA unique GUI | ENA unique GUI | ENA unique GUI | ENA unique GUI | Common VNA GUI | Common VNA GUI |

## 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

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