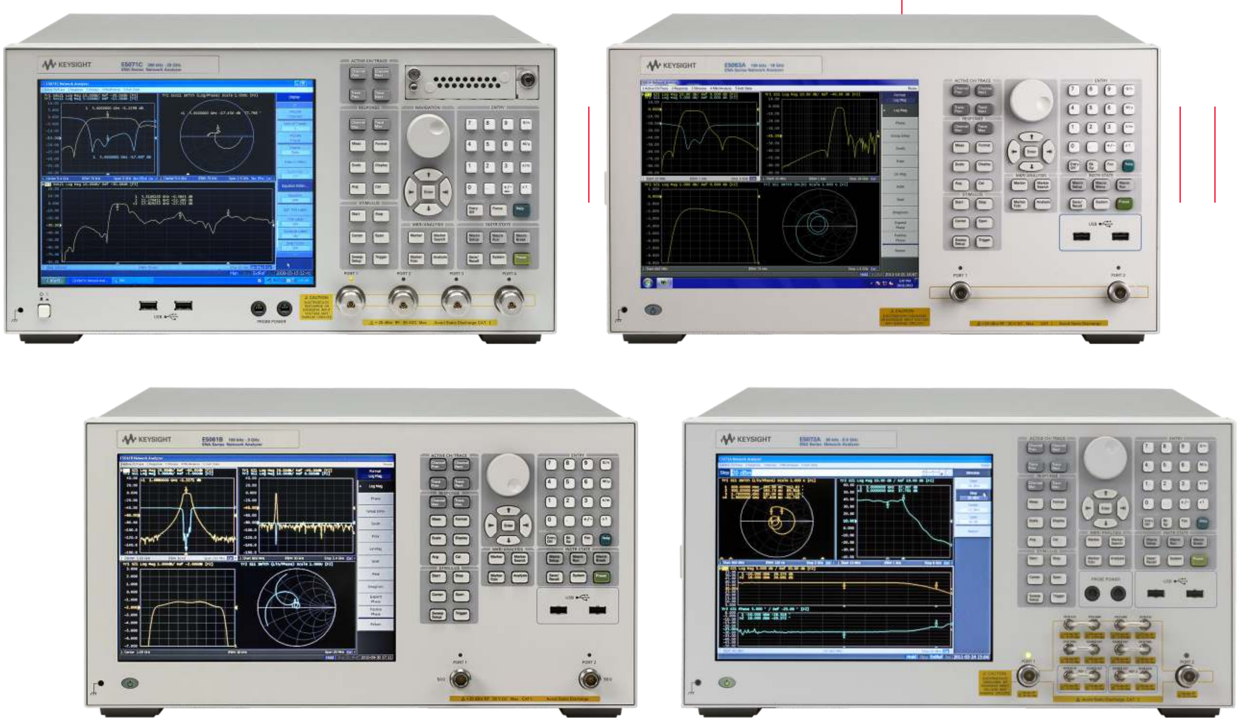
# Keysight Technologies
# Drive Down the Cost of Test Using the ENA Series of Network Analyzers

Application Note



KEYSIGHT TECHNOLOGIES

# Introduction

From the 1970s onward, the growth of personal computers and consumer electronics equipment for home and personal use has increased dramatically. Additionally, the price for these types of equipment has been decreasing year by year with a steady increase in competition. The top priority of each manufacture in this industry is the same -- how to reduce manufacturing costs.

For many years the acquisition of test and measurement equipment and the costs of testing in the production lines were viewed as a necessary evil. However, the importance of testing has been increasing in proportion with technology advancements, such as product complexity and size. As a result, reducing the cost of test for production lines is very difficult to achieve.

In this application note, we discuss the contributions of Keysight Technologies, Inc.'s ENA Series of Vector Network Analyzers (ENA, hereafter) to drive down the cost of test in production lines.

## Agenda:

- Total cost of ownership (TCO) and Cost of test (COT)
- Value of ENA
- TCO simulation with ENA
- Conclusion

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

The recent boom of smart-phones, feature phones, tablet PCs, and flat screen televisions has generated intense competition between manufactures of final products and components/ modules used in these products. The product life-cycle has been getting shorter and shorter with the continuous price reduction in the market. How to reduce costs maintaining and/or increasing the quality of products is indispensable and there is only one way to win.

## Total cost of ownership

Total cost of ownership (TCO, hereafter) 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. Operating expenses provide an area for much greater latitude in terms of what is included in the TCO model. The following lists the element in the operating expenses:

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

## Cost of test

Cost of test (COT, hereafter) is defined the total cost to be spent for an equipment in the testing process in production lines at a specific timing. (i.e. test and measurement equipment, automatic component handling machines, etc.). COT varies during the useful life of the equipment as shown in figure 1. Figure 1 shows the change of COT from t0 to t3. At the acquiring timing t0, COT consists of capital expenses and initial operating expenses like training and education in addition to other costs (a). At t1, the capital expenses still remain as depreciation expenses, but initial operating expenses are removed. After t2, capital expenses are removed and maintenance expenses are 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).

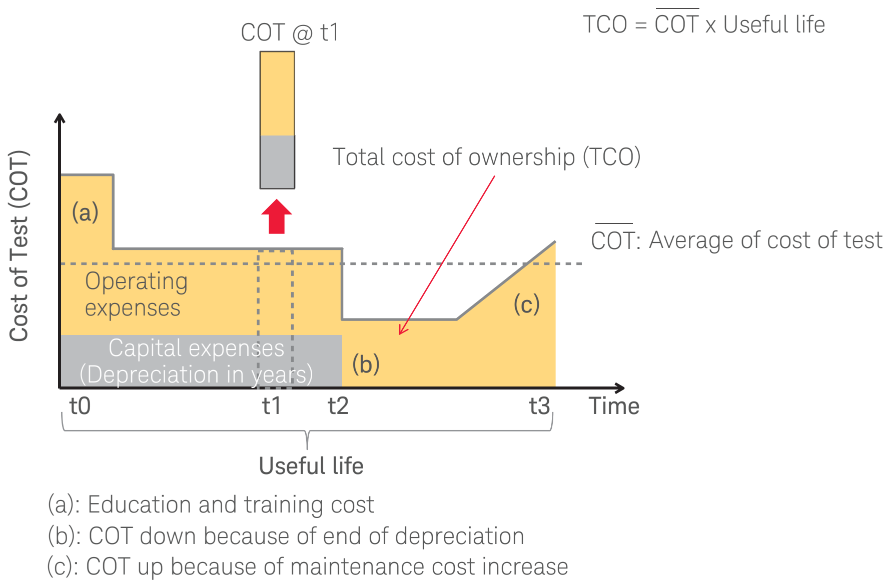



Figure 1. Change of cost of test

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

After the 1990s, manufacturing costs have been going down due to manufacturers striving to meet market prices to remain competitive as shown in figure 2. Manufacturing costs is nowadays about one-fifth of that in early 1990s. However, the COT has not changed and is almost the same as it was twenty years ago, due to the fact that test and measurement requirements in the production lines have become more complex to test advanced technology performance.

In the total cost of a product, it is reported 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 win the business in this very competitive market.

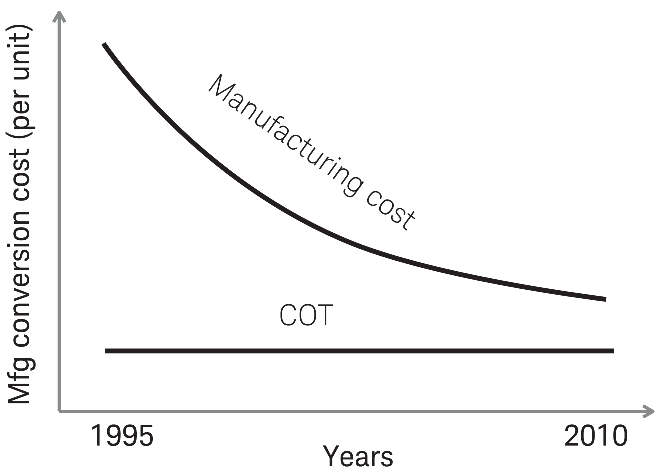



Figure 2. Cost of manufacturing vs. COT

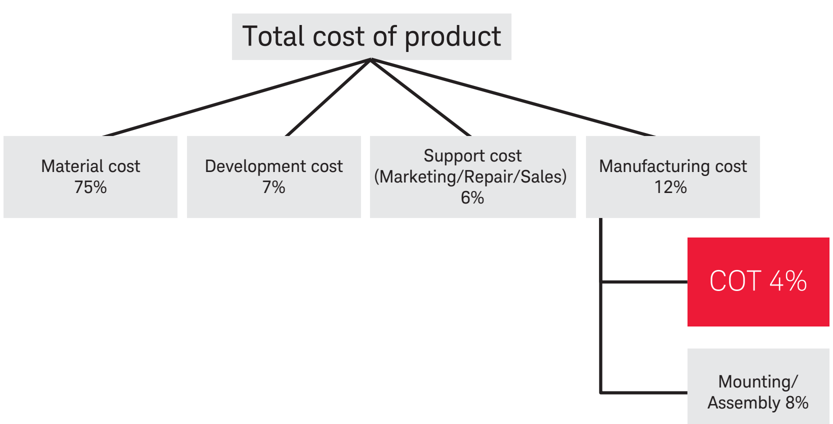



Figure 3. Total cost of product

COT is influenced and varied by the performance and quality of the testing and the measurement equipment used in the production lines. This formula is used to approach the COT by structured method:

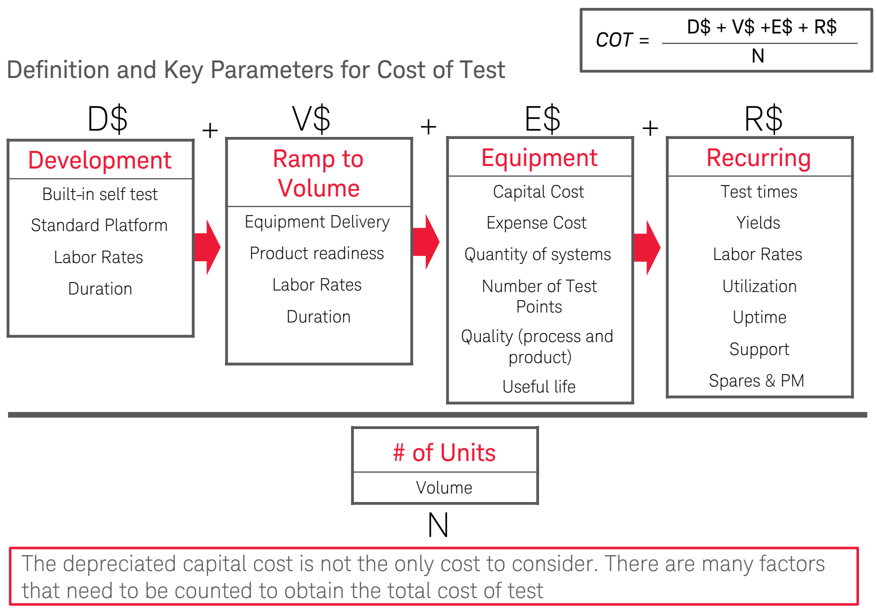



Figure 4: Definition and key parameters for Cost of Test

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. All engineering support for test, verification, mechanical preparation is in it. Procurement and purchasing costs and management costs are also included.

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), and COT per one device under test is calculated by this formula.

## Vector network analyzer in COT

This application note focuses on the contributions vector network analyzers provide (VNA hereafter) 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

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 is heavily impacts the COT factor.

Because each VNA has different attributes, every VNA has different contributions to the COT. The next section discuss how the ENA can contribute to drive down COT.

# Value of ENA

## Fast speed, small trace noise, and superior stability

ENA has remarkable advantages relating to operating costs, explained in previous section. Additional advantages include the acquisition costs against former HP/Agilent VNAs (i.e., 8753 series) and other VNAs in the market. Overall, ENA can help you reduce COT.

ENA is designed specifically for use in production lines of electrical components and modules. ENA contributes to minimize the COT in production lines by shortening the test time and increasing the yield, and leads the way to reduce the costs of products, components, and modules.

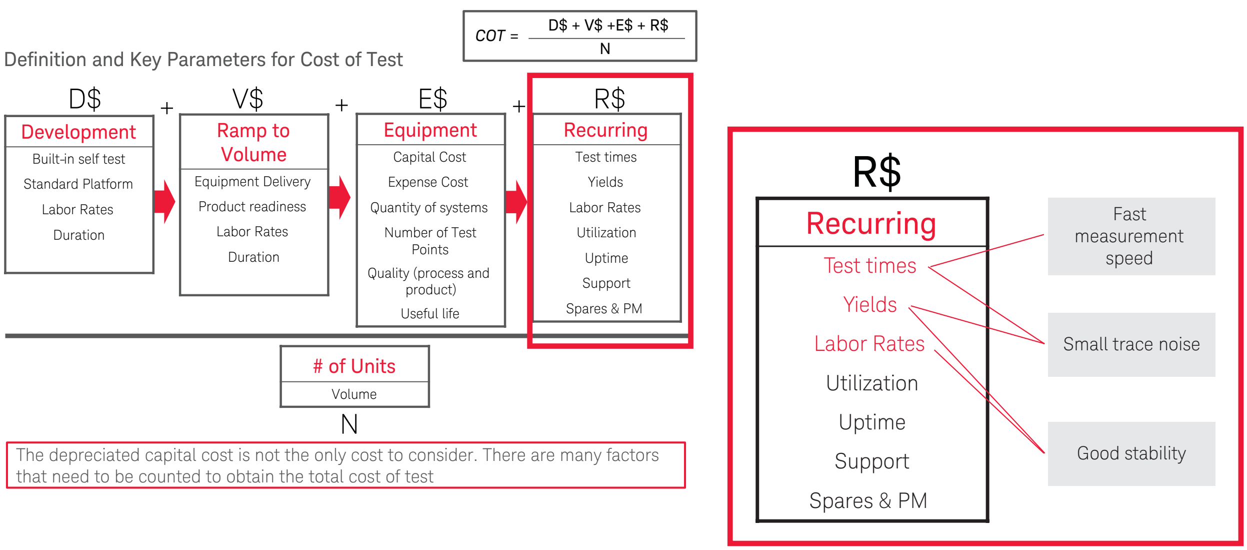



Figure 5.

First, let's see how the ENA's fast measurement speed, small trace noise, and superior stability contributes to decreasing the COT in production lines.

Measurement speed, trace noise, and stability are related to the test times and yields heavily as shown in table 1. We will discuss each of them in the following section.

# Typical Examples of ENA Contributions to Drive Down the COT

## Fast measurement speed


Figure 6. Measurement speed comparison: 1601 points, full 2-port cal, 1 GHz to 1.2 GHz IFBW = 6 kHz (8753ES), 500 kHz (E5071C and E5072A)

The measurement throughput (the time taken to test one DUT) directly impacts the COT. However, the test requirements have been becoming complex and precise according to the trend of increasing complexity and high performance and quality of DUTs. As a result, even in the testing in production lines, the test limit has been becoming strict and the measurement speed has not been able to increase due to necessity of very detailed measurements. For example, with SAW filter tests which is used in handset devices, millisecond order measurements are required to produce huge amounts of devices. To achieve this, recent VNAs have a wider RBW (IFBW), faster measurement and CPU performance, and faster error calculation compared to the legacy VNAs. Segment sweep function also helps users to tailor the sweep condition so that minimum but necessary test point is measured. Reducing measurement time fluctuation is also important for fast measurement time testing, because the fluctuation limits the maximum performance of auto-test and handling machines. The ENA was designed to minimize the measurement time fluctuation and provide one of the most stable measurement times in the market. Another key factor for fast SAW filter/duplexer measurement is having a small trace noise for its pass band test under fast measurement condition. We'll discuss detail about it in the following section, but E5071C ENA can measure a single-ended to balanced SAW filter by up to 3 times faster than other comparable VNAs in the market.

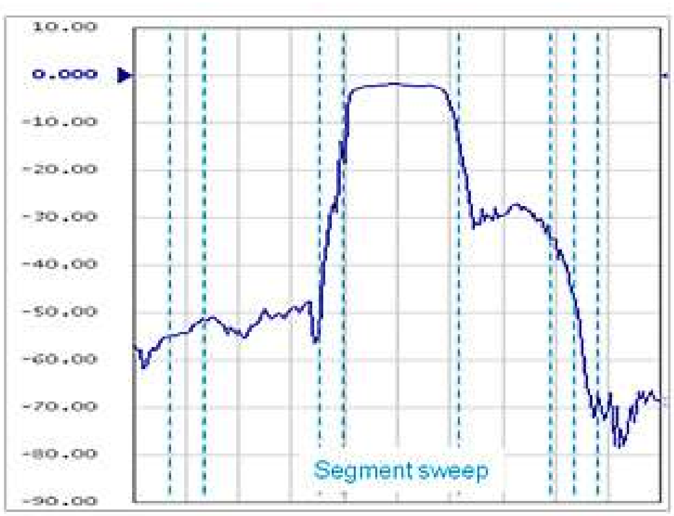



Figure 7. Segment sweep

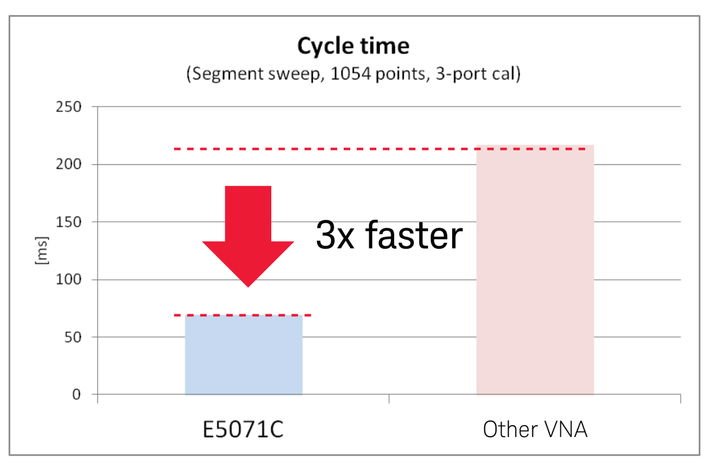



Figure 8. Total cycle time example

In case of the filter testing which is used in the base transceiver stations (BTS) of wireless communication infrastructure, both the insertion loss and rejection band measurements must be done at a time and this requires a very wide dynamic range. To measure the rejection performance, a VNA often needs to have more than 120 dB dynamic range. Normally, this measurement needs to use very narrow RBW to cover a wide dynamic rage, but using the narrow RBW takes measurement time. If a VNA has a small measurement uncertainty, the wider RBW can be used and the measurement time is gets shorter.

In addition to the superior stability, the ENA minimizes the uncertainty of measurements thanks to the quality of circuit design and measurement algorithm. As a result, to get the same dynamic range, ENA can use a wider RBW than other VNAs and this makes the measurement throughput shorter than other VNAs. For example, in the test of high-rejection BTS filters that requires > 120 dB dynamic range, E5072A ENA shows 16 times faster throughput than other comparable VNAs in the market.

## Small trace noise

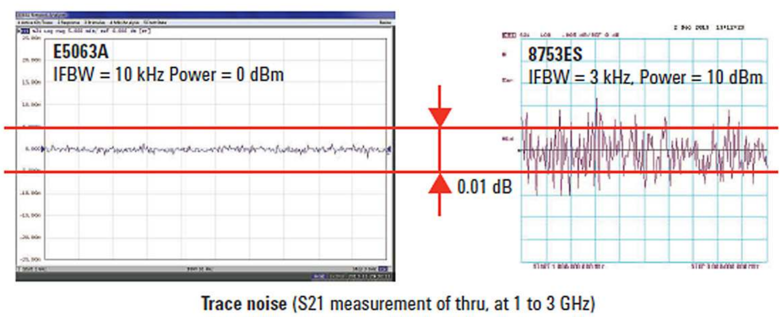



Figure 9. Trace noise comparison

At the high signal level measurement, like pass-band evaluation of the filter, high-level trace noise is one of the important factors that impacts accurate test and yield. This is because large high-level trace noise reduces tolerant of the test margin. Thus it's important for users to check and keep the trace noise level small enough at DUT's test frequency so that misjudgments don't happen during the test. Because high-level trace noise is proportional to SQRT(RBW), you can maintain the trace noise small by selecting narrower RBW. Because ENA has smaller high-level trace noise than other comparable VNAs in the market, ENA can use a wider RBW than other VNAs to have the same amount of trace noise, and this also makes the measurement throughput shorter than other VNAs.

## Superior measurement stability

Stability shows that immunity of an instrument from the changes of the measurement environment, such as the time and temperature. The stability performance is one of the key specifications which show the design quality of an instrument.

In the production lines, an instrument often runs continuously around the clock (24 hrs x 7 days) to produce the planned numbers of DUTs. However, the environment around the instrument is unfortunately not stable during the production, and fluctuates. To get a stable measurement result in such a fluctuating environment, it is indispensable that the instrument has a superior stability performance. If using an unstable instrument, frequent recalibration is necessary and the line must be stopped and this increases the downtime.

Also, the uncertainty of a measurement result which is caused by the instability of an instrument must be added to the tolerances of a go-no-go limit in testing in addition to the uncertainty of DUTs. This directly impacts to the decrease of the yield of production lines and increases the COT.

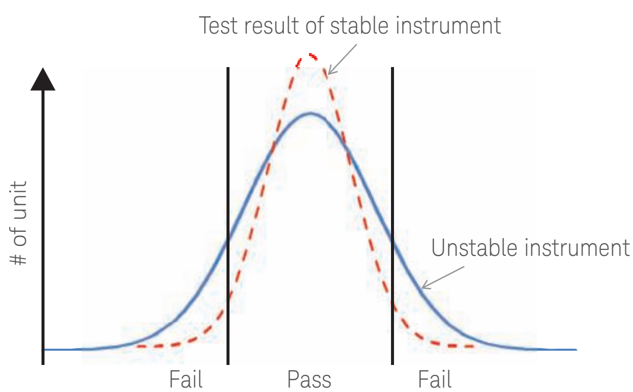
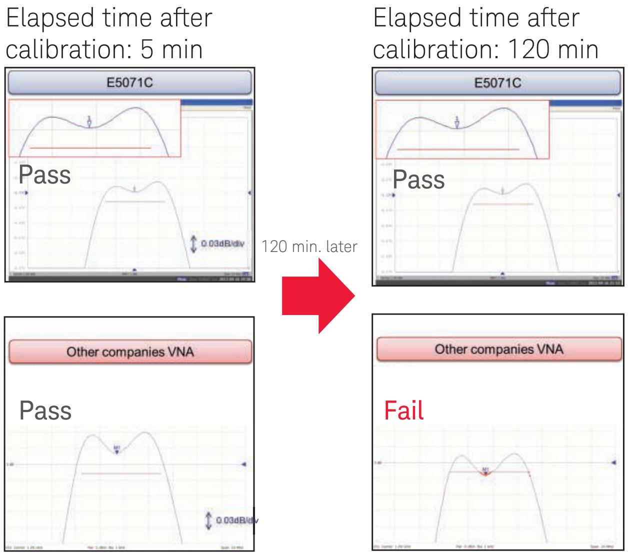



Figure 10. Stability impacts the yield

ENA has a superior stability performance compare to other VNAs in the current market. ENA helps reduce downtime and increases the production yield. Figure 11. shows the measurement fluctuation comparison of the pass band of a filter in a certain time. The fluctuation of ENA (E5071C in this case) is very small against that of other VNAs.

## Good stability




Better stability ensures the better test quality.

More straightforward, better stability reduces the frequency of calibration which means engineers can save time and cost

Figure 11. Stability comparison. Other company's VNA shows fail after 120 minutes later.

## See how ENA's superior stability and lower trace noise reduces COT

This is a simulation example that shows how the ENA's 4 times better stability and 10 times better trace noise compared to the 8753ES series contributes to reduce the COT.

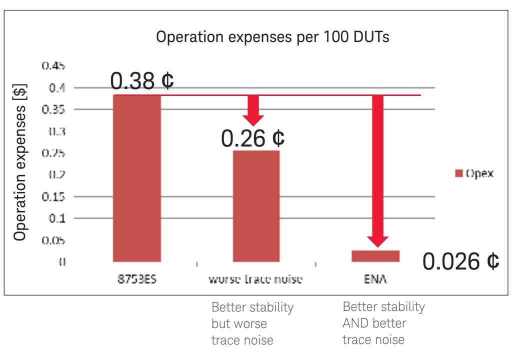
Assumption is that a customer has been testing using the 8753ES series vector network analyzer. For the required test, 8753ES takes 20 seconds for one DUT test.

The left bar in the following figure shows operation cost when testing 100 DUTs by the 8753ES. The cost was calculated as 0.38 cents for each 100 DUTs.

Then middle bar shows what if there is a VNA with 4 times better trace noise but at the same trace noise level. Thanks to the good stability, the calibration period can be extended. This increases the average throughput and reduces the COT by 33 % or 0.12 cents. Additionally, the good stability reduces technicians' work time by 45 minutes per day because of less calibration requirements, and it allows them more time for other tasks.

The right bar shows ENA's assumption with 4 times better stability and 10 times better trace noise than that of 8753ES. Better trace noise allows you to use wider IFBW but still keeps the same level of yield. In this calculation, it reduces COT by 93% or 0.354 cents per 100 DUTs test.

## Operation expenses per 100 DUTs – High volume manufacturing case




- x4 better stability reduce COT by 33% or - 0.13 ¢ per 100 tests
- Technician has 45 minutes free time per day because of less calibration time

- x4 better stability AND x10 better trace noise reduces COT by 93% or - 0.36 ¢ per 100 tests
- Technician has 45 minutes free time per day because of less calibration time

Figure 12. Operation expense simulation

## Other aspects reducing COT

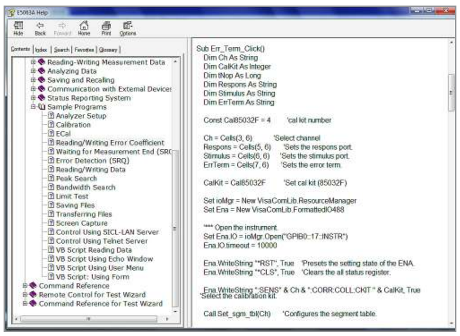
Here are other ENA values to reduce COT in various stages.

## Reduce development costs

Many sample programs and easy-to-access embedded/web help files (operation manual) helps reduce development cost of the production line.

Common command structure in the ENA series using industry standard SCPI structure helps write programing code easily with a small amount of education and training time.

### 50 sample programs on the help and web



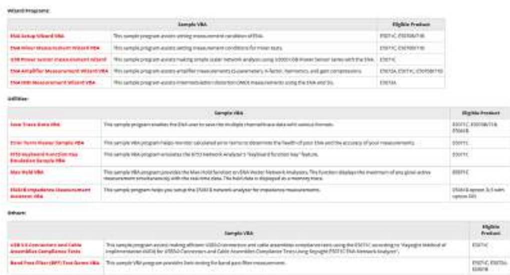
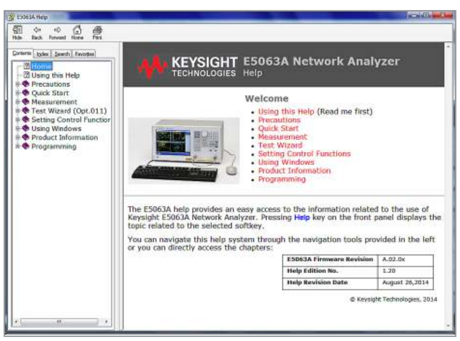


Figure 13. sample programs example

### Quick access to the help file and search target command



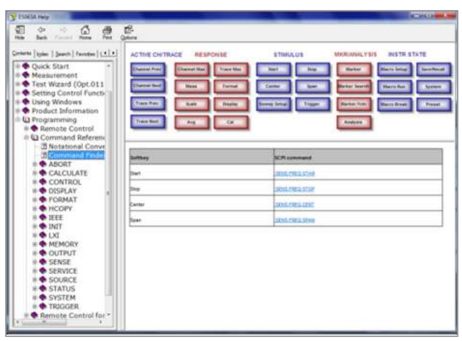



Figure 14. Embedded help file and command find page

### Drop-in legacy VNAs by code translator (E5071C/72A)

The E5071C and E5072A have an 8753 code compatible mode in which the analyzer automatically translates the 8753's remote programming commands for operation on the E5071C/E5072A. This enables you drop-in replacement in the automated test environment.

## Reduce ramp to volume

### Short delivery time

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.

## Reduce equipment expense

### 3-year standard warranty


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.

### Upgradeability


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.

### Re-sale value

Keysight products have credible resale value as shown in the figure below in commercial second-hand market. Also we have a program to buy old equipment from you when you buy a new VNA from Keysight. Please contact your sales representative for details.

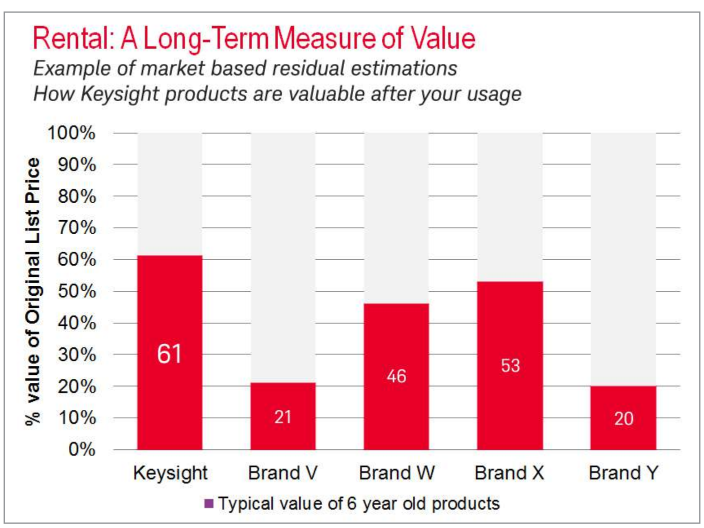



Figure 15. Typical price selling in the second market

# TCO Simulation with ENA

Here shows a scenario when introducing ENA in the production line instead of the 8753 series by using trade-in promotion program. As shown below, the scenario shows a positive NPV under a 10% capital cost.

## High volume test

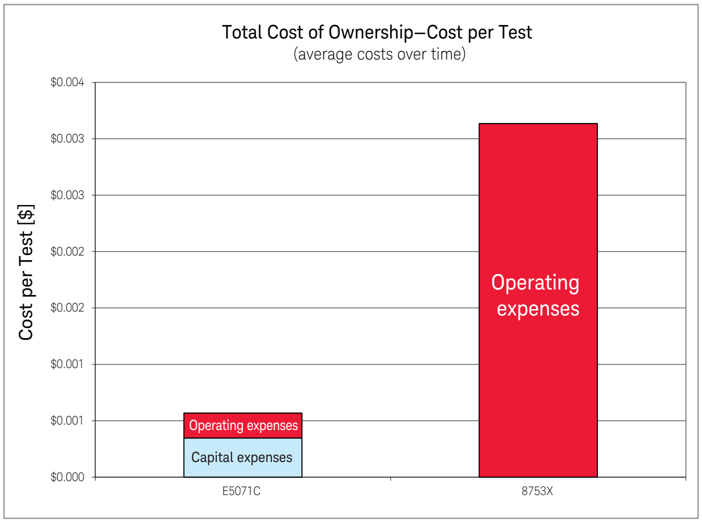



Figure 16. TCO - Cost per test comparison

| | Yr0 | Yr1 | Yr2 | Yr3 | Yr4 | Yr5 | Yr6 | Yr7 | Yr8 | Yr9 | Yr10 | Yr11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Purchase | 39,542 | | | | | | | | | | | |
| T-in credit | (13839) | | | | | | | | | | | |
| Depreciation | | (7,908) | (7,908) | (7,908) | (7,908) | (7,908) | | | | | | |
| Opex delta | | 25,011 | 25,011 | 25,011 | 25,011 | 25,011 | 25,011 | 25,011 | 25,011 | 25,011 | 25,011 | |
| Resale | | | | | | | | | | | | 10810 |
| Pre-tax profit | | 17,103 | 17,103 | 17,103 | 17,103 | 17,103 | 25,011 | 25,011 | 25,011 | 25,011 | 25,011 | 10,810 |
| Corpolate tax (20%) | | (3,421) | (3,421) | (3,421) | (3,421) | (3,421) | (5,002) | (5,002) | (5,002) | (5,002) | (5,002) | (2,162) |
| after-tax progit | | 13,682 | 13,682 | 13,682 | 13,682 | 13,682 | 20,009 | 20,009 | 20,009 | 20,009 | 20,009 | 8,648 |
| **Free cash flow** | | | | | | | | | | | | |
| Depreciation | | 7,908 | 7,908 | 7,908 | 7,908 | 7,908 | | | | | | |
| Capital spending | (25,703) | | | | | | | | | | | |
| FCF | | 21,590 | 21,590 | 21,590 | 21,590 | 21,590 | 20,009 | 20,009 | 20,009 | 20,009 | 20,009 | 8,648 |
| PV of FCF | 106,269 | <-- -25,703 + NPV(10%,FCF Yr1 to Yr11) | | | | | | | | | | |
| Capital cost | 10% | | | | | | | | | | | |

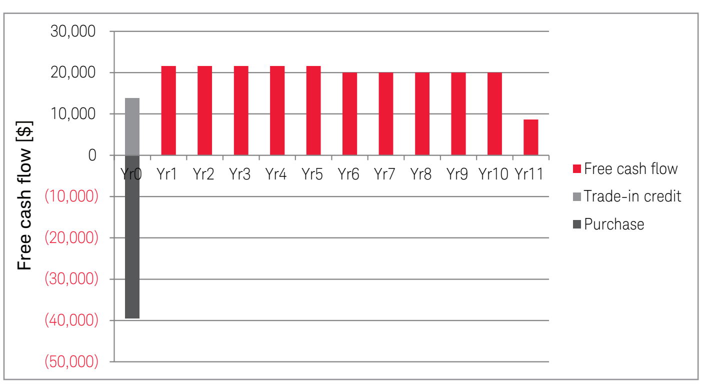



Figure 17. Free cash flow simulation

| Product comparison | E5071C and 8753ES |
|---|---|
| DUT | Component test for handset, like SAW filter or duplexer |
| Assumption | E5071C can measure x10 faster than the 8753ES, corporate tax 20%, capital cost 10%, depreciation 5 years |
| Operating expense cost reduction per test | - 96% |
| Cash flow/yr and NPV impact | CF +$20k/yr, NPV +$106k |
| Opportunities | 2-port to multi-port testing. Multi-site test for further fast through-put and lowers the cost. |

Considering the risk that the operation expense becomes larger for old equipment after the support period, replacing the legacy equipment with a new one at the proper time will be a critical business decision.

# Conclusion

We discussed the definition of TCO and COT in this application note, then shown that the vector network analyzer is one of a key contributors to reduce COT of your DUT.
The Keysight ENA is a mid-performance VNA series with superior cost performances in the current market. 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.

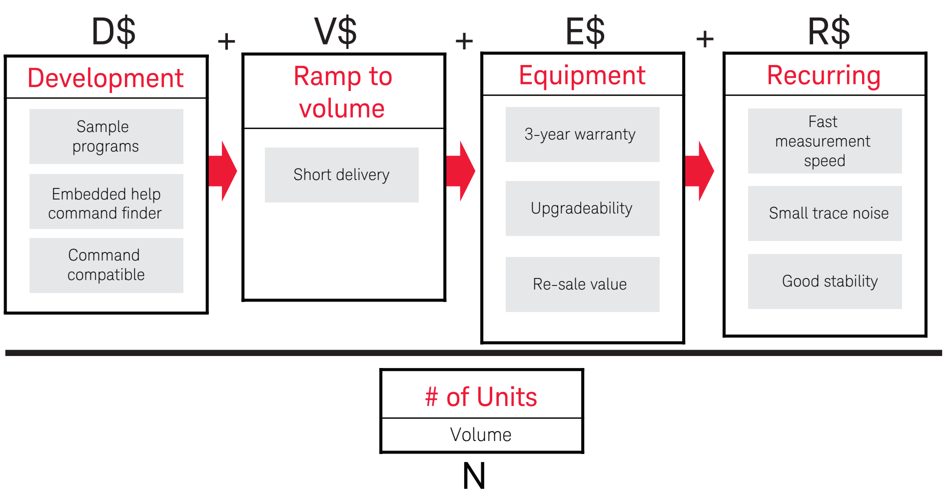



Figure 18. ENA contribution to drive down the cost of test

# References and Links

For the latest line-up of the ENA series network analyzer, visit
**http://www.keysight.com/find/ena**

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

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,
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| India | 1 800 112 929 |
| Japan | 0120 (421) 345 |
| Korea | 080 769 0800 |
| Malaysia | 1 800 888 848 |
| Singapore | 1 800 375 8100 |
| Taiwan | 0800 047 866 |
| Other AP Countries | (65) 6375 8100 |

**Europe & Middle East**

| | |
|---|---|
| Austria | 0800 001122 |
| Belgium | 0800 58580 |
| Finland | 0800 523252 |
| France | 0805 980333 |
| Germany | 0800 6270999 |
| Ireland | 1800 832700 |
| Israel | 1 809 343051 |
| Italy | 800 599100 |
| Luxembourg | +32 800 58580 |
| Netherlands | 0800 0233200 |
| Russia | 8800 5009286 |
| Spain | 0800 000154 |
| Sweden | 0200 882255 |
| Switzerland | 0800 805353 |
| | Opt. 1 (DE) |
| | Opt. 2 (FR) |
| | Opt. 3 (IT) |
| United Kingdom | 0800 0260637 |

For other unlisted countries:
www.keysight.com/find/contactus
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Published in USA, October 11, 2014
5992-0195EN
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