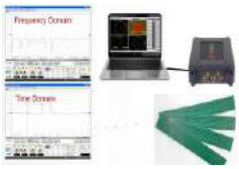
KEYSIGHT



利用新型態網路分析儀的TDR功能測試PCB板的線路阻抗

林 文 生 / Vincent Lin, 應用工程部 / 品勛科技
July 27, 2022

KEYSIGHT TECHNOLOGIES Authorized Distributor

PINSYUN

Agenda

- TDR Fundamentals
- New NA TDR Solution – Keysight P937xB
- Demo

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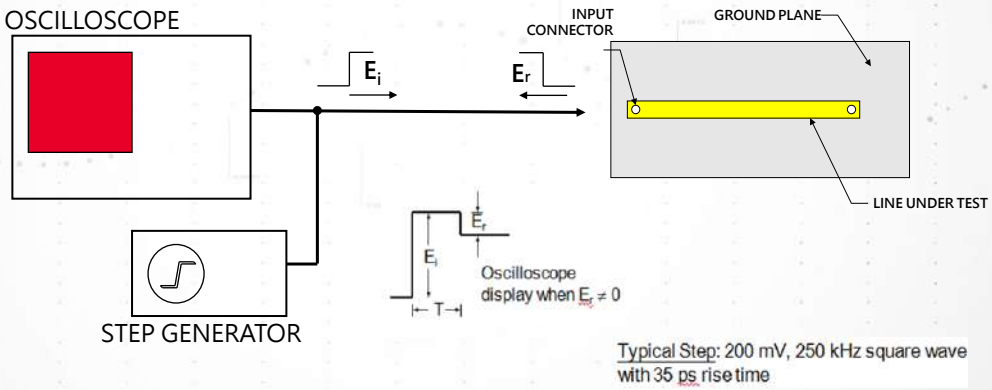
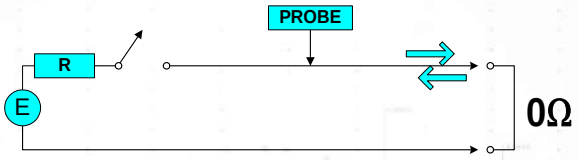
TDR Basic

Time Domain Reflectometry

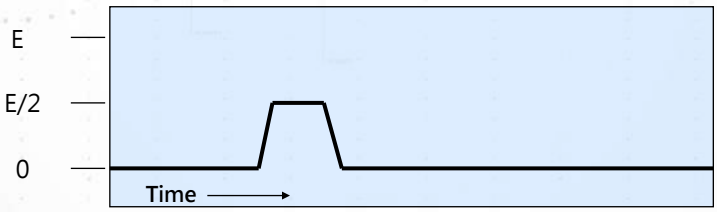
A TDR sends a voltage step down a line and monitors the line for reflections



Short Termination



What do you expect to see at the probe before, during, and after you close the switch?



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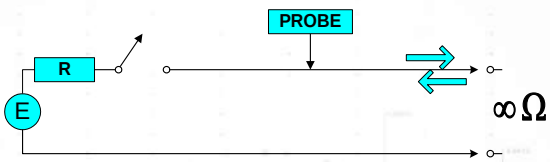
Open Termination



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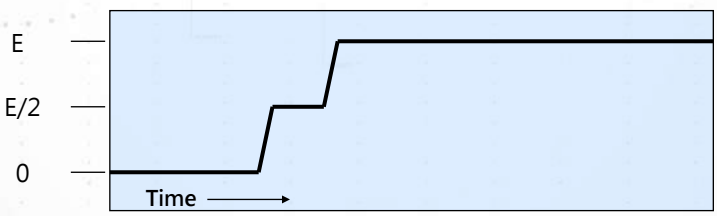

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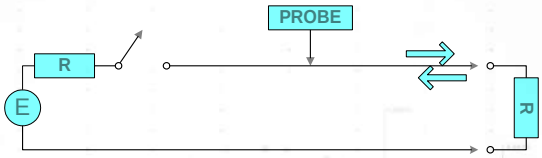
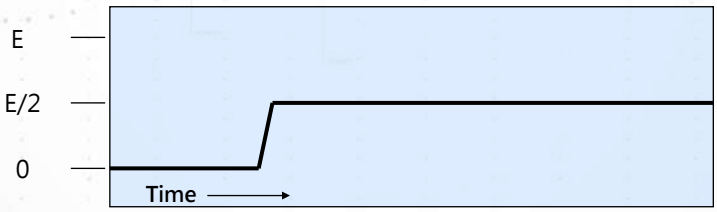
Perfect Termination



What do you expect to see at the probe before, during, and after you close the switch?



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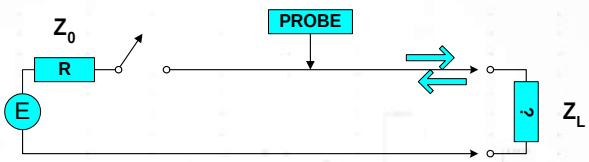
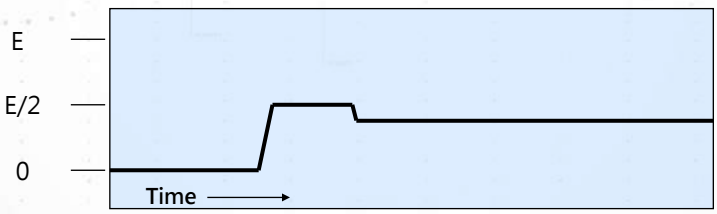
Unknown Termination



Is the unknown resistor closer to a short (zero Ω) or an open (∞ Ω)?



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Impedance Mismatch Terms

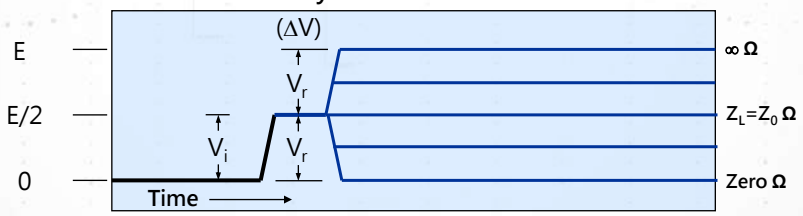
$$Z_L = Z_0 \frac{1+\rho}{1-\rho}$$

Impedance Calculated from Source Impedance and Reflection Coefficient.

$$\rho = \frac{V_r}{V_i}$$

Reflection Coefficient, rho: How much was reflected?

What is the value of Zload?
The DCA automatically calculates this for us.



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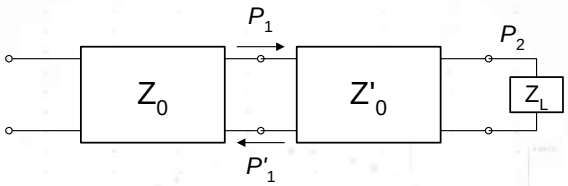
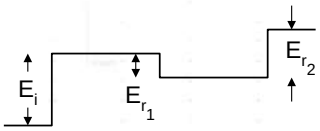
Cables with Multiple Discontinuities



$$P_1 = \frac{Z_0' - Z_0}{Z_0' + Z_0} \qquad P_2 = \frac{Z_L - Z_0'}{Z_L + Z_0'}$$



Accuracy decreases as you look further down a line with multiple discontinuities

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Locating mismatches

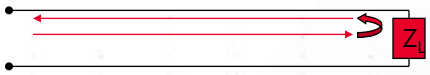
- Distance Formula
- Where

  v_p = velocity of propagation

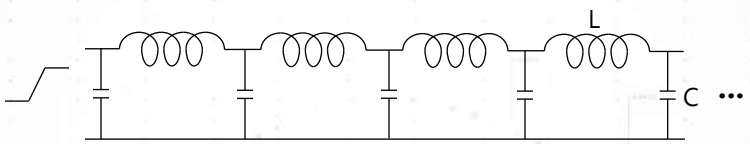
  T = transit time from monitoring point to the mismatch and back

$$D = \upsilon_p \cdot \frac{T}{2}$$

Why is the transit time divided by two?



In Summary - Discontinuities Cause Problems



$$Z_O = \sqrt{L/C}$$

Discontinuities occur when the impedance changes. This will happen when the L or C changes or an R is introduced.

Interconnects-Using Excess L/C the EASY Way

- Given
  Excess L/C from the previous slide...
- Calculate the Capacitance required to minimize reflections in a 50 Ohm system
  - excess inductance increases Zo
  - excess capacitance decreases Zo

$$Z_O = \sqrt{L/C} \qquad C = \frac{L}{Z_0^{\,2}}$$

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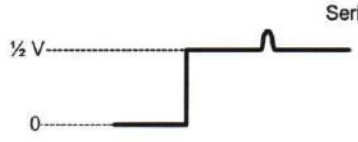
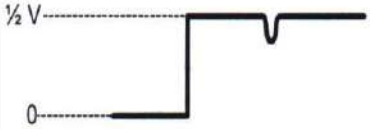
Interconnects-Using Excess L/C the EASY Way

Series L discontinuity



$$L = \frac{1}{2}\int_{t_1}^{t_2} Z(t)\,dt$$

Shunt C discontinuity



$$C = \frac{1}{2}\int_{t_1}^{t_2} \frac{1}{Z(t)}\,dt$$

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What is TDT?

- Time Domain Transmission
- A way to launch a fast edge into a DUT and look at the shape of the edge after passing through the DUT
- Benefits
  - Measure Propagation Delay
  - Measure TDT gain (loss/attenuation)
  - Measure Risetime degradation
- Very useful for monitoring crosstalk
  - Move monitoring electrical channel to adjacent lines
  - Near End Crosstalk (NEXT) and Far End Crosstalk (FEXT)

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Rise Time and Distance Resolution

- Rise time limits distance resolution
- What system rise time is needed to identify discontinuities on an outer trace of FR4 PCB separated by 5 mm?

$$d_{\min} = \frac{c}{\sqrt{e_r}} \frac{t_r}{2} \qquad t_r = \frac{2d_{\min}\sqrt{e_r}}{c}$$

d_{min} = minimum separation between discontinuities
t_r = system rise time
e_r = dielectric constant
c = speed of light in a vacuum = 299,792,458 m/s

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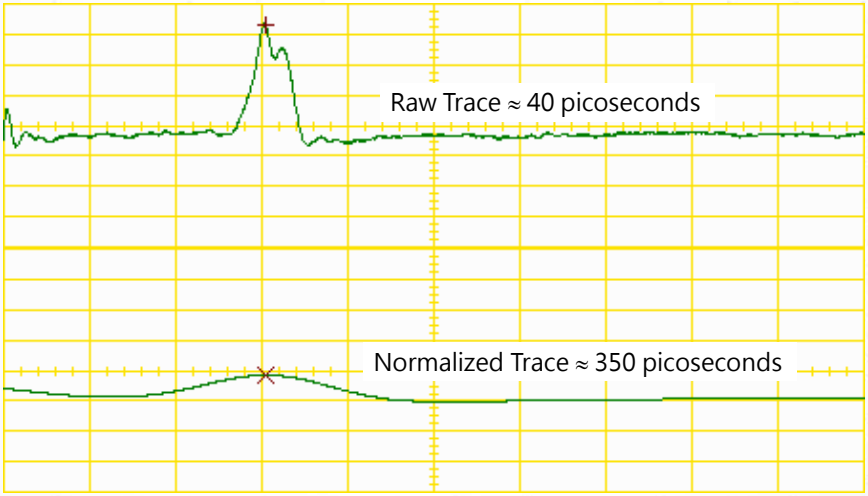
Rising Time and Distance Resolution compare



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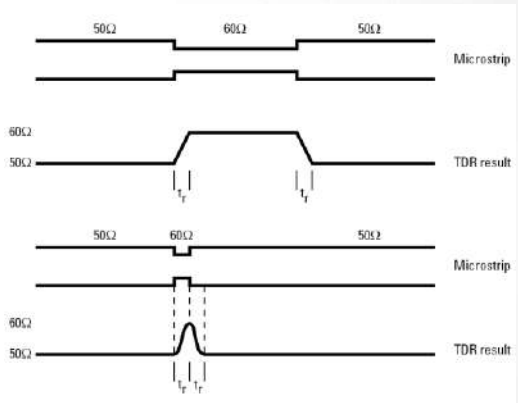
How close can two reflection sites be and still be seen as independent events?

- The TDR edge needs time to reach its full height before the next event is encountered
- So what determines the two-event resolution?
- Answer: It' s not just the TDR step speed!



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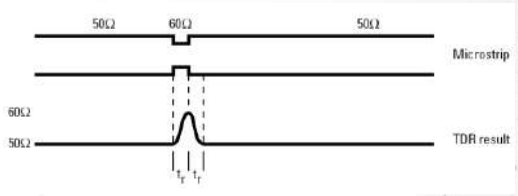
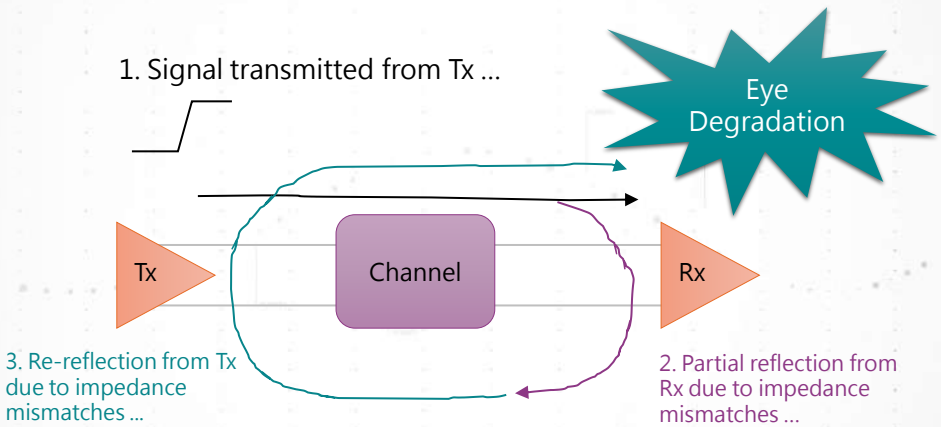
Two-event resolution is dependent upon several things

- The ***system*** rise time is dependent on the step speed, the scope receiver, and any cabling
- The time on the TDR display represents ***roundtrip*** time. One way time is half of this
- Resolution is a ***distance*** parameter, so propagation velocity is needed (set by effective propagation velocity/dielectric constant of material)



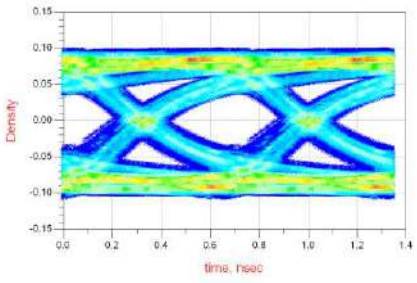
$$\frac{c \bullet t_{rise}}{2\sqrt{\varepsilon}}$$

Hot TDR Measurements

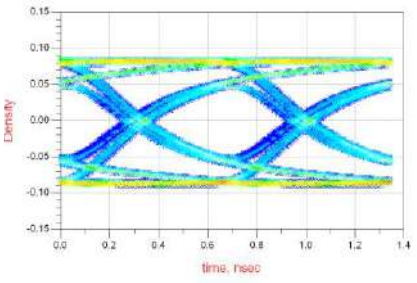


Hot TDR Measurements

Source Termination Effects



Source Impedance NOT Matched



Source Impedance Matched

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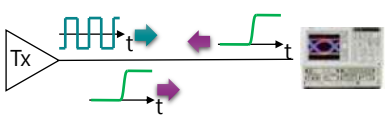
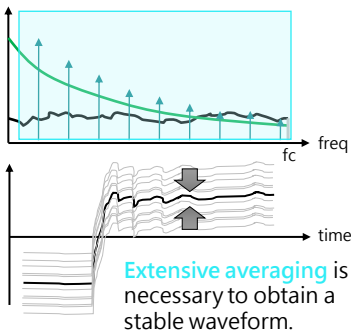
Fast and Accurate Measurements

TDR Scopes

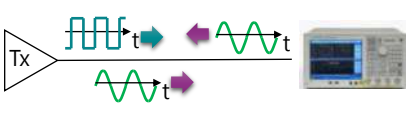


•wideband receiver captures all of the signal energy from the transmitter

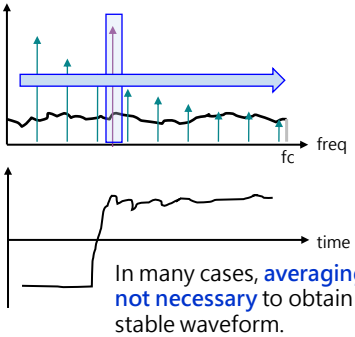


Extensive averaging is necessary to obtain a stable waveform.

ENA Option TDR



•narrowband receiver minimizes the effects of the data signal from the transmitter



In many cases, averaging is not necessary to obtain a stable waveform.

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Agenda

- TDR Fundamentals
- New NA TDR Solution – Keysight P937xB
- Demo

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Keysight P93xxB Streamline Series Vector Network Analyzer

P938xB (4-port, 9 or 20 GHz)

P937xB (2-port, up to 44 GHz)

Compact Form.
Zero Compromise.

Key Features

- Small, compact form factor **in just *one* hand**
- Same calibration and metrology across all trusted Keysight VNAs
- **Common GUI** with the modern Keysight VNAs
- Ability to configure a **multiport VNA** by stacking two VNAs (S97551B software is required)

Qualification Criteria

P937xB and P938xB are recommended when:

- Testing 2- or 4-port RF passive devices
- Basic functions are just enough
- mmWave measurements are needed at an affordable price
- Small form factor is must for easily sharing between test locations

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P937xB and P938xB Streamline Series VNA

YOUR SOLUTION TO MEASUREMENT CHALLENGES

- Broad Selection of VNAs that Meet Your Needs
- Low-cost mmWave Tests
- Extending the Number of Ports

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Broad Selection of VNAs that Meet Your Needs

7 frequency models for 2-port P937xB and two frequency models for 4-port P938xB.

P937xA Series
2-port up to 26.5 GHz

P9370A: 300 kHz to 4.5 GHz
P9371A: 300 kHz to 6.5 GHz
P9372A: 300 kHz to 9 GHz
P9373A: 300 kHz to 14 GHz
P9374A: 300 kHz to 20 GHz
P9375A: 300 kHz to 26.5 GHz

P937xB Series NEW!
2-port up to 44 GHz

P9370B: 9 kHz to 4.5 GHz
P9371B: 9 kHz to 6.5 GHz
P9372B: 9 kHz to 9 GHz
P9373B: 9 kHz to 14 GHz
P9374B: 9 kHz to 20 GHz
P9375B: 100 kHz to 26.5 GHz
P9377B: 100 kHz to 44 GHz

P938xB Series NEW!
4-port up to 20 GHz

P9382B: 9 kHz to 9 GHz
P9384B: 9 kHz to 20 GHz

Note: Frequency upgrade is planned for P937xB or P938xB (up to 20 GHz), or from 26.5 to 44 GHz model. The unit must be returned to Keysight' s service center for retrofit.

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P9377B… Keysight’ s Lowest-cost 44 GHz VNA

Key Performance @ 40 GHz	
Dynamic range (10 Hz IFBW)	> 102 dB
Trace noise	< 0.0072 dBrms (10 kHz IFBW)
Stability (typ.)	0.01 dB/deg.C
Cycle time (typ.)	15 msec (201 pts, 2-port cal)

Overview

- Full 2-port VNA (controlled via Thunderbolt 3)
- 100 kHz to 44 GHz
- Test ports with 2.4 mm connectors

Target applications

- General-purpose passive component tests (ex. antennas, filters, connectors,)
- 5G mmWave components
- Materials measurement tests with N1500A software

Balance good performance and cost to cover wide frequency

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Use Case – mmWave Low-loss Dielectric Measurement

5G MATERIALS CHARACTERIZATION

Materials measurement solution example

Split cylinder resonator
(ex.)
- N1501AKEAD-728 (28 GHz SCR)
- N1501AKEAD-740 (40 GHz SCR)

Measurement challenges and needs:
- Accurate measurements of low-loss material properties in mmWave frequency ranges (ex. 5G FR2 28 / 39 GHz)
- One complete solution (ex. VNA, test fixture and software) is needed.
- Simple and easy to use

Keysight’ s product/solution benefits or advantages

1. Various measurement methods and test fixtures are offered depending on materials under test and frequency ranges.
2. Resonate cavity method is the best method for low-loss thin film materials measurements.
3. Intuitive N1500A software shows step-by-step instructions.

Source: N1500A technical overview (link)

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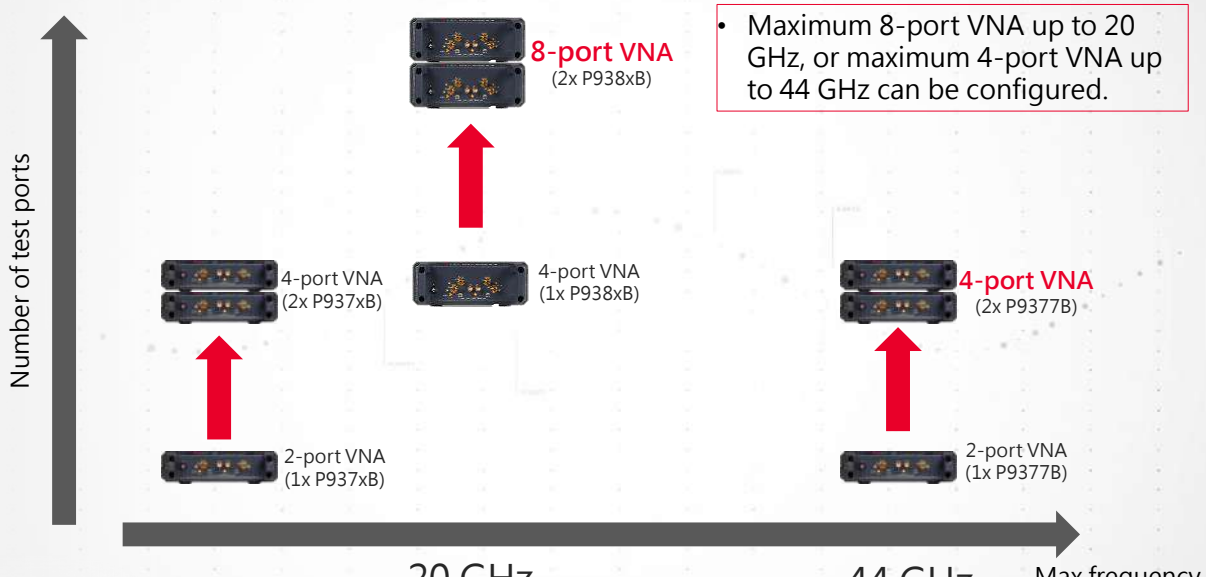
Stack Two VNAs for More Ports



- Maximum 8-port VNA up to 20 GHz, or maximum 4-port VNA up to 44 GHz can be configured.

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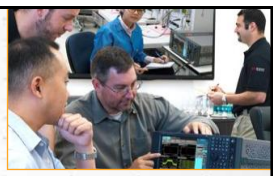
Use Case – Education, RF laboratory

GENERAL-PURPOSE PASSIVE COMPONENT TESTS



Streamline Series VNA (ex. P937xB)

2-port

DUT examples
- Antennas
- Filters
- Cables
- Connectors
  :

4-port

DUT example:
- Balanced devices (ex. SAW filters)
- Differential cables
- Dividers, duplexers, couplers with >3 ports
  :

Measurement challenges and needs:
- Low cost
- Easy to share
- Wide coverage of component tests
- Same measurement science and compatibility with industry-standard VNAs (ex. PNA-X, ENA)

Keysight' s product/solution benefits or advantages

1. Ease of use for faster learnings; supports same GUI and measurement science as all trusted Keysight VNAs.
2. Ability to extend the number of ports by cascading two VNA instruments
3. Good performance at low cost

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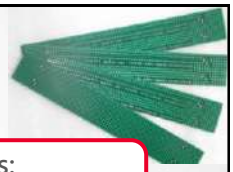
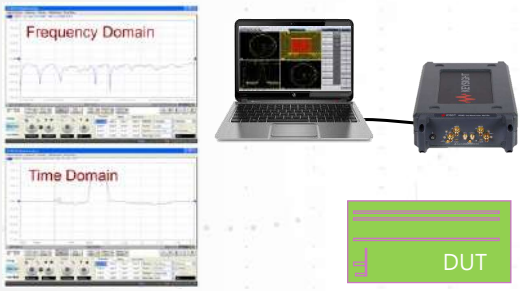
Use Case – PCB Manufacturing Test

BOTH TIME-DOMAIN AND FREQUENCY-DOMAIN TESTS



P93xxB VNA + S97011B enhanced time-domain analysis with TDR software



- DUT: New PC boards (flexible PCB or FPC)
- Industries: Electronic devices, cell phones, IoT, automotive
- Test parameters: differential impedance (Tdd11), differential return loss (Sdd11/22), differential insertion loss (Sdd21)

Measurement challenges and needs:
- **Multiport** = differential input and differential output ports (4x single-ended ports)
- Both time-domain (ex. impedance) and frequency domain (S-parameters) measurements
- Wide frequency (for narrow resolution in time domain)
- Low cost for maintenance

Keysight' s product/solution benefits or advantages

1. 4-port VNA (Max 20-GHz with a P9384B or Max 44 GHz with two P9377Bs and S97551B)
2. Seamless measurements using enhanced time-domain analysis with TDR software (S97011B)
3. Accurate calibrated measurements using ECal
4. ESD robustness with VNA-based architecture

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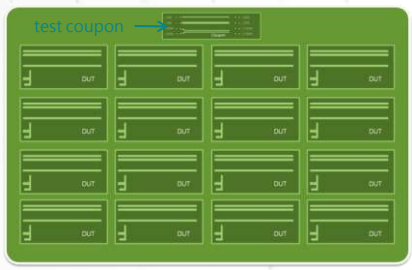
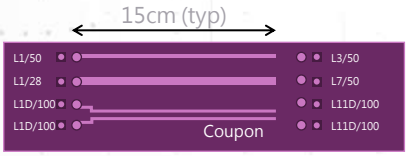
Traditional PCB Measurements

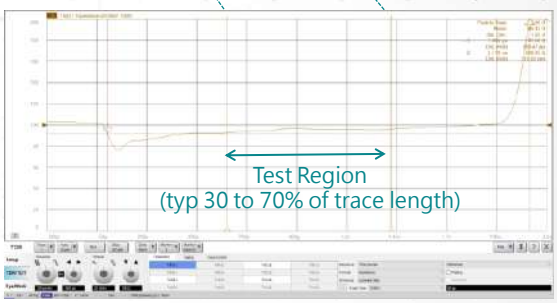


•Test Coupon Example:



•Parameters = Impedance (SE & DIFF)
•Required Tolerance = ±10%

•L1/50 trace measurement example



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Key Specifications of TDR

Bandwidth	Spec.	53 GHz	44 GHz	32 GHz	26.5 GHz
Input impedance	Nom.	50 ohm			
DC damage level at test port	Spec.	35 V			
Maximum test port input voltage (Hot TDR mode)	Typ.	1.5 V (100 kHz to 20 GHz) 0.9 V (20 GHz to 30 GHz) 0.7 V (30 GHz to 40 GHz) 0.5 V (40 GHz to 53 GHz)	1.5 V (100 kHz to 20 GHz) 0.9 V (20 GHz to 30 GHz) 0.7 V (30 GHz to 40 GHz) 0.5 V (40 GHz to 44 GHz)	1.5 V (100 kHz to 20 GHz) 0.9 V (20 GHz to 30 GHz) 0.7 V (30 GHz to 32 GHz)	1.5 V (100 kHz to 20 GHz) 0.9 V (20 GHz to 26.5 GHz)
TDR stimulus[1]	Nom.	Step, Impulse			
TDR step amplitude[2]	Nom.	1 mV to 5 V			
TDR step rise time[3] (min) (10% to 90%)	Spec.	8.42 ps	10.2 ps	14 ps	16.9 ps
TDR step response resolution in free space[4] (εr = 1) (min)	Nom.	1.3 mm	1.5 mm	2.1 mm	2.5 mm
TDR impulse width (min)[3]	Spec.	11.4 ps	13.8 ps	18.9 ps	22.8 ps
TDR deskew range (max)[5] (test cable length)	Typ.	50 ns	50 ns	50 ns	50 ns
DUT length (max)[6]	Spec.	1.25 µs	1.25 µs	1.25 µs	1.25 µs
TDR stimulus repetition rate (max)	Spec.	52.9 MHz	43.9 MHz	31.9 MHz	26.4 MHz
RMS noise level[7]	Typ.	120 µVrms	80 µVrms	80 µVrms	80 µVrms
Eye diagram data rate (max)[8]	Spec	42.4 Gb/s	35.2 Gb/s	25.6 Gb/s	21.2 Gb/s

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Key Specifications of TDR

Bandwidth	Spec.	20 GHz	18 GHz	14 GHz	9 GHz	6.5 GHz	4.5 GHz
Input impedance	Nom.	50 ohm					
DC damage level at test port	Spec.	35 V					
Maximum test port input voltage (Hot TDR mode)	Typ.	1.5 Vpp					
TDR stimulus[1]	Nom.	Step, Impulse					
TDR step amplitude[2]	Nom.	1 mV to 5 V					
TDR step rise time[3] (min) (10% to 90%)	Spec.	22.3 ps	24.8 ps	31.9 ps	49.6 ps	68.6 ps	99.1 ps
TDR step response resolution in free space[4] (εr = 1) (min)	Nom.	3.3 mm	3.7 mm	4.8 mm	7.4 mm	10.3 mm	14.9 mm
TDR impulse width (min)[3]	Spec.	30.2 ps	33.6 ps	43.1 ps	67.1 ps	92.9 ps	135 ps
TDR deskew range (max)[5] (test cable length)	Typ.	50 ns	50 ns	50 ns	50 ns	50 ns	50 ns
DUT length (max)[6]	Spec.	13.8 µs	13.8 µs	13.8 µs	13.8 µs	13.8 µs	13.8 µs
TDR stimulus repetition rate (max)	Spec.	19.9 MHz	17.9 MHz	13.9 MHz	8.9 MHz	6.4 MHz	4.4 MHz
RMS noise level[7]	Typ.	60 µVrms	60 µVrms	60 µVrms	60 µVrms	60 µVrms	60 µVrms
Eye diagram data rate (max)[8]	Spec.	16 Gb/s	14.4 Gb/s	11.2 Gb/s	7.2 Gb/s	5.2 Gb/s	3.6 Gb/s

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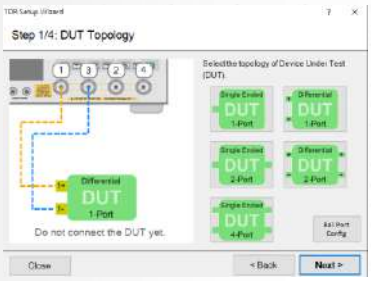
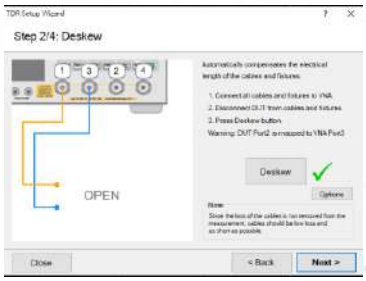
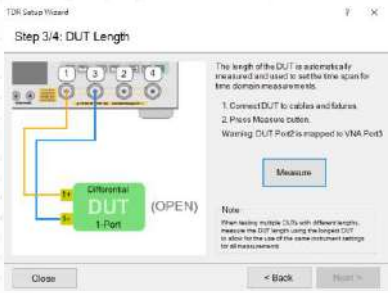
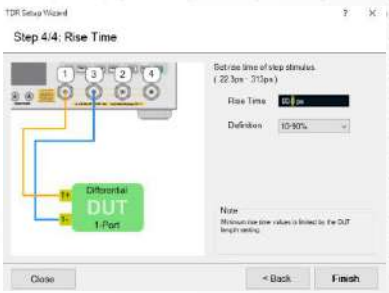
Setup Wizard guides









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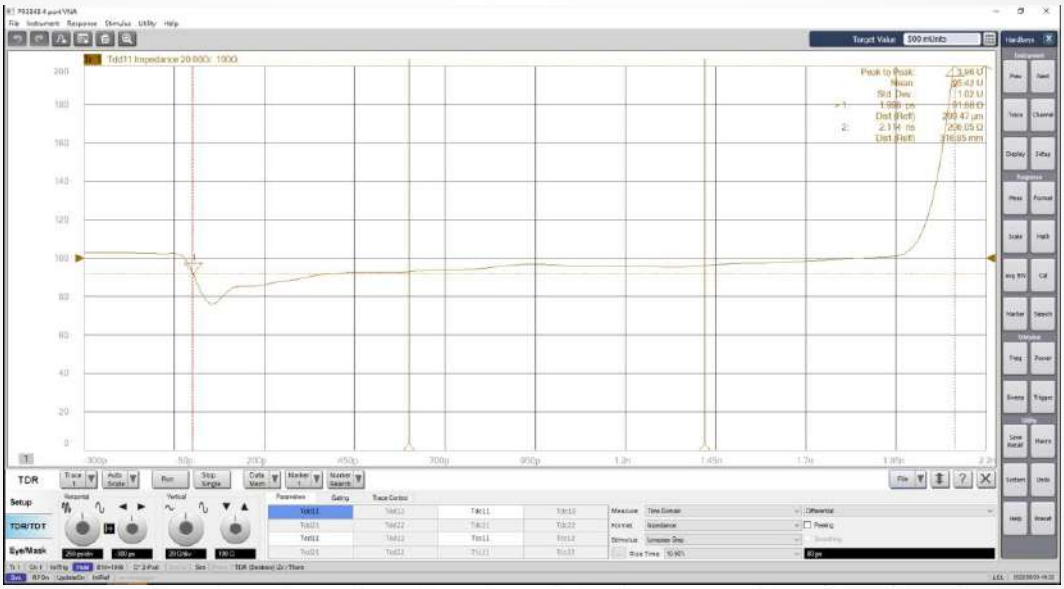
TDR Measurement



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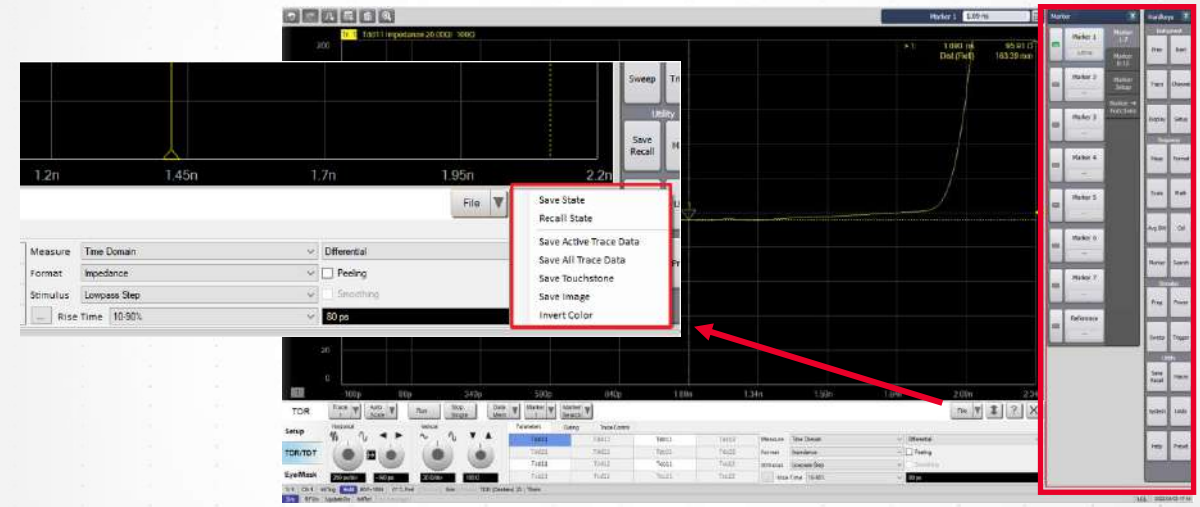
TDR Measurement



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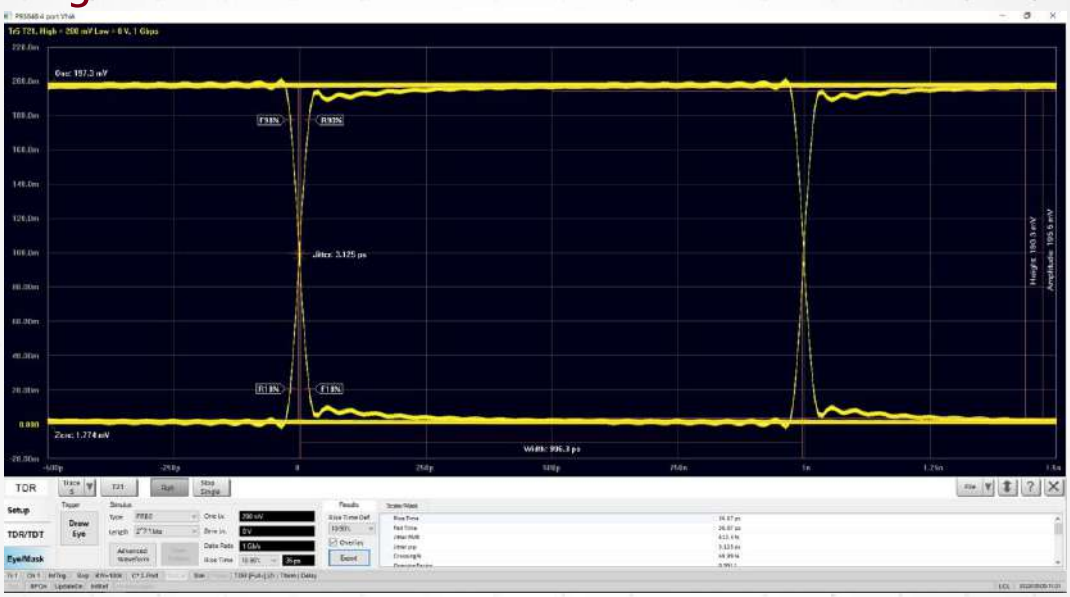
Eye Diagram



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Eye Diagram

Eye Setting

	A	B	C
1	# VNA Option TDR Simulated Eye Results		
2	# 2022/5/5 鋒 ? 11:00:04		
3	#		
4	Level Zero	0.001774	
5	Level One	0.197308	
6	Level Mean	0.099541	
7	Amplitude	0.195534	
8	Height	0.190313	
9	Width	9.96E-10	
10	Opening Factor	0.9911	
11	Signal / Noise	112.3584	
12	Duty Cycle Distortion	6.62E-15	
13	Duty Cycle Distortion (%)	0.000662	
14	Rise Time	3.67E-11	
15	Fall Time	3.67E-11	
16	Jitter (PP)	3.13E-12	
17	Jitter (RMS)	6.12E-13	
18	Cross Point (%)	49.99112	
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Eye Results

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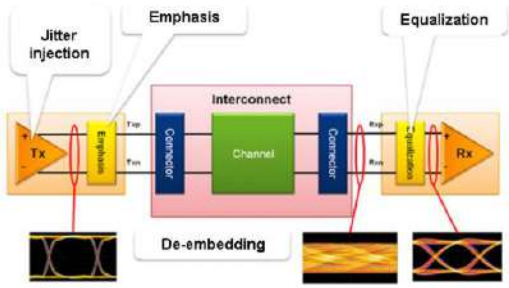
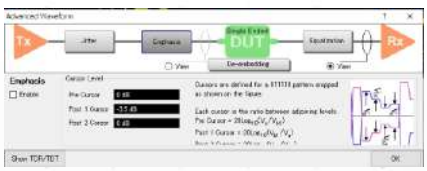
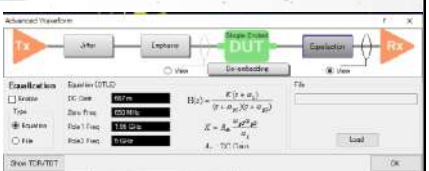
Advanced Waveform Analysis







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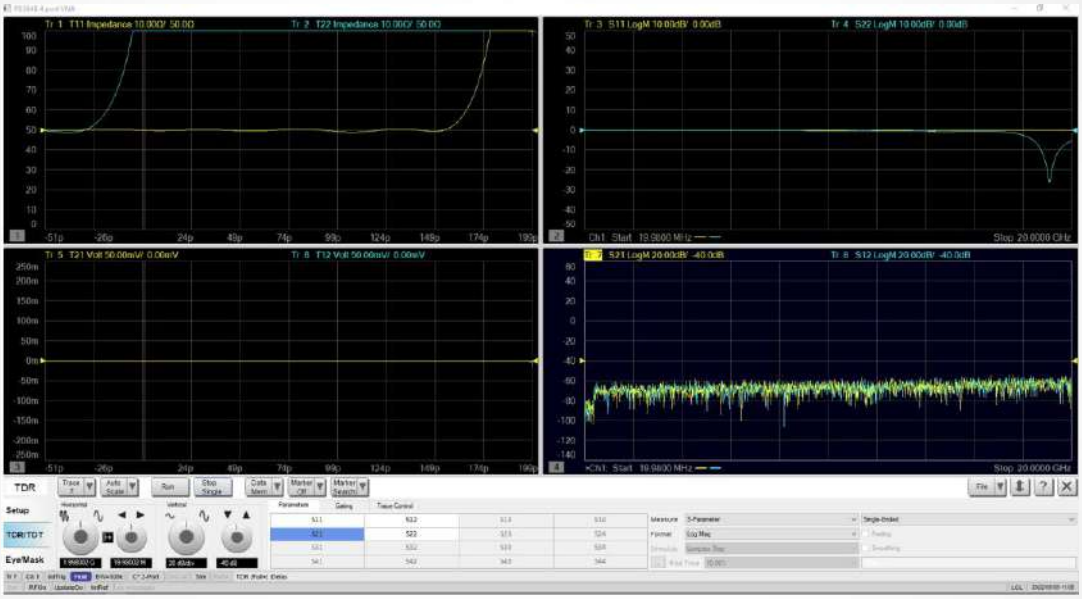
TDR and S Parameter Simultaneously



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Agenda

- TDR Fundamentals
- New NA TDR Solution – Keysight P937xB
- Demo

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瞭解更多資訊，請訪問

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http://www.pinsyun.com.tw

是德科技：

http://www.keysight.com.tw

或致電 品勛科技：

台北：02-2278-9886

新竹：03-668-1808

台南：06-230-0896

Thank You !

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