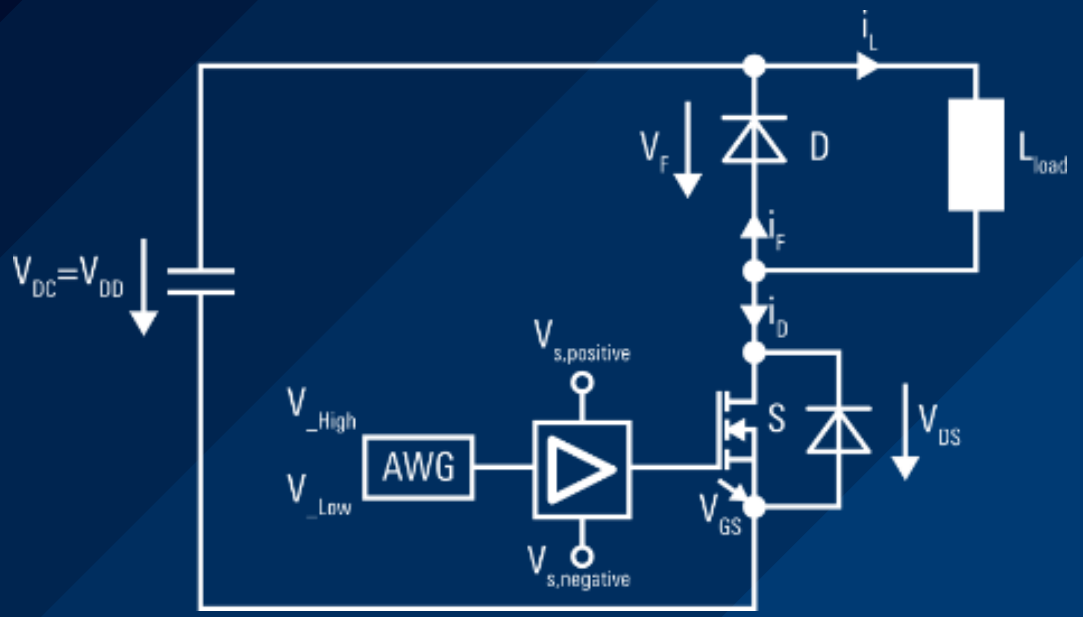
2023 寬能隙半導體之設計及雙脈衝測試研討會

新一代示波器與雙脈衝測試

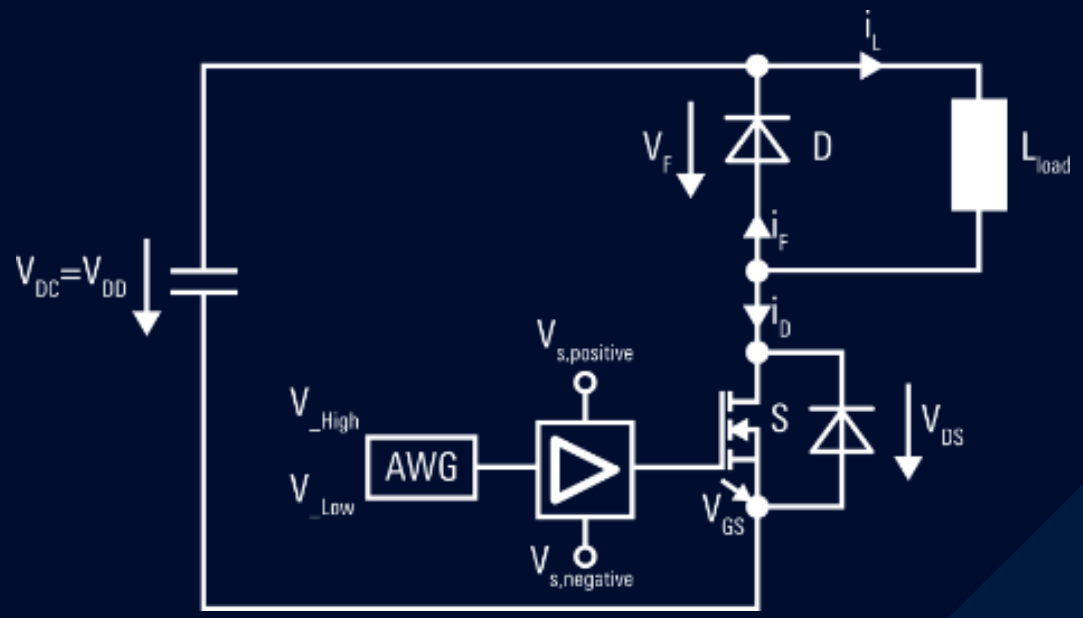
CS Wong 黃俊雄
Product Manager (Oscilloscope)
示波器產品經理



ROHDE&SCHWARZ
Make ideas real

OUTLINE

- Overview of Double Pulse Test 雙脈衝測試概述
- Double Pulse Test Setup 雙脈衝測試設置
- Today’s oscilloscope 示波器新功能
- Example of measurements 測量範例



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OVERVIEW OF DOUBLE PULSE TEST
雙脈衝測試概述

DOUBLE-PULSE TESTING 雙脈衝測試
MANY USE-CASES 應用

Datasheet generation

Maximum ratings

1 Maximum ratings

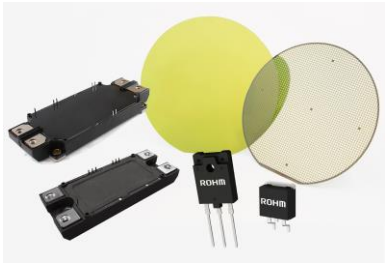
For optimum lifetime and reliability, Infineon recommends operating conditions that do not exceed 80% of the maximum ratings stated in this datasheet.

Table 2 Maximum ratings

Parameter	Symbol	Value	Unit
Drain source voltage, $T_{vj} \geq 25°C$	V_{DSS}	1200	V
DC drain current for $R_{th(j-c,max)}$, limited by T_{vjmax}, $V_{GS} = 18V$, $T_C = 25°C$ $T_C = 100°C$	I_D	 56 47	A
Pulsed drain current, t_p limited by T_{vjmax}, $V_{GS} = 18V$	$I_{D,pulse}$[1]	169	A
DC body diode forward current for $R_{th(j-c,max)}$, limited by T_{vjmax}, $V_{GS} = 0V$ $T_C = 25°C$ $T_C = 100°C$	I_{SD}	 56 36	A
Pulsed body diode current, t_p limited by T_{vjmax}	$I_{SD,pulse}$[1]	169	A
Gate-source voltage[2] Max transient voltage, < 1% duty cycle Recommended turn-on gate voltage	V_{GS}	-7… 23 15… 18	V

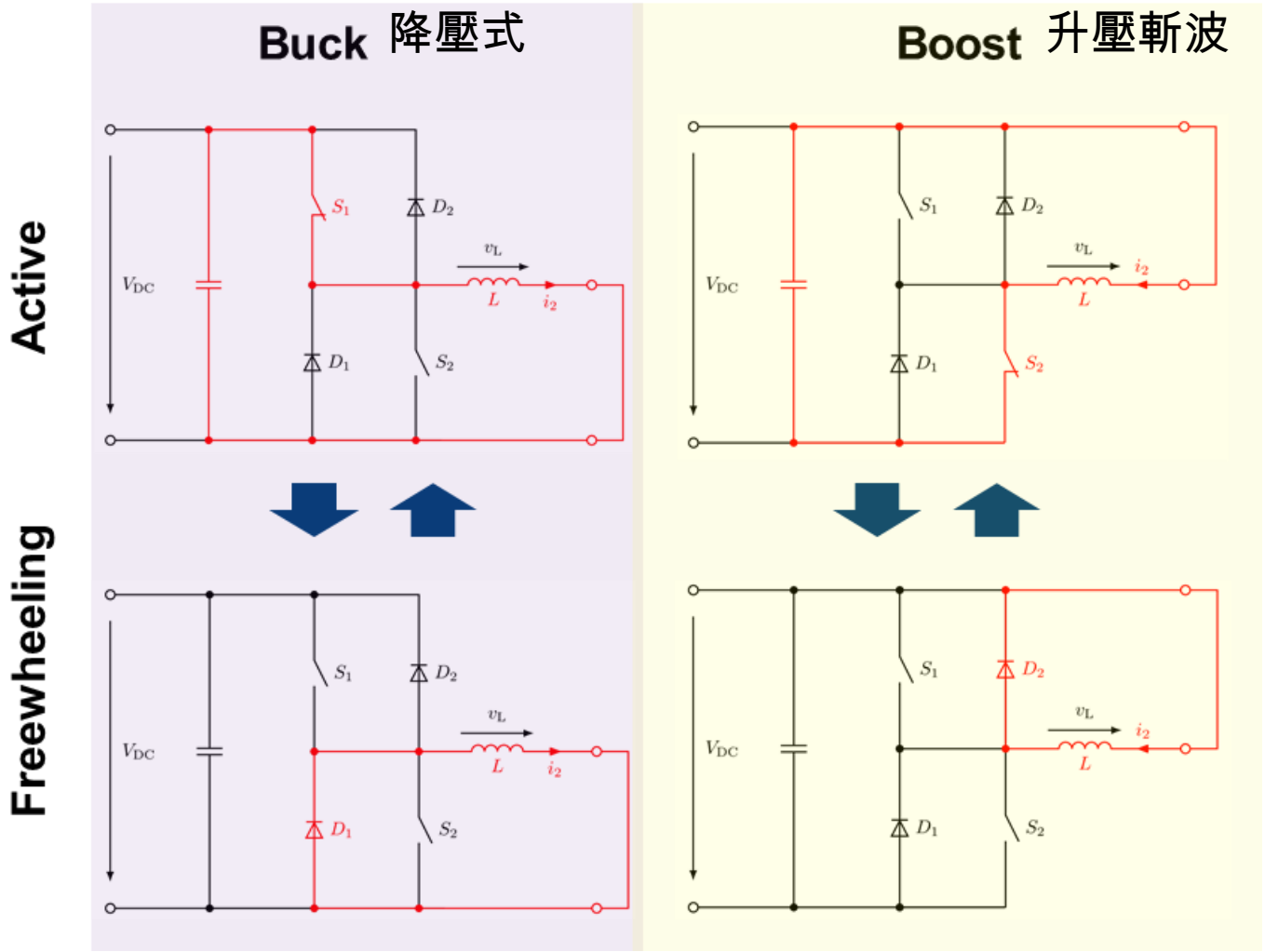
Module production test

Module selection



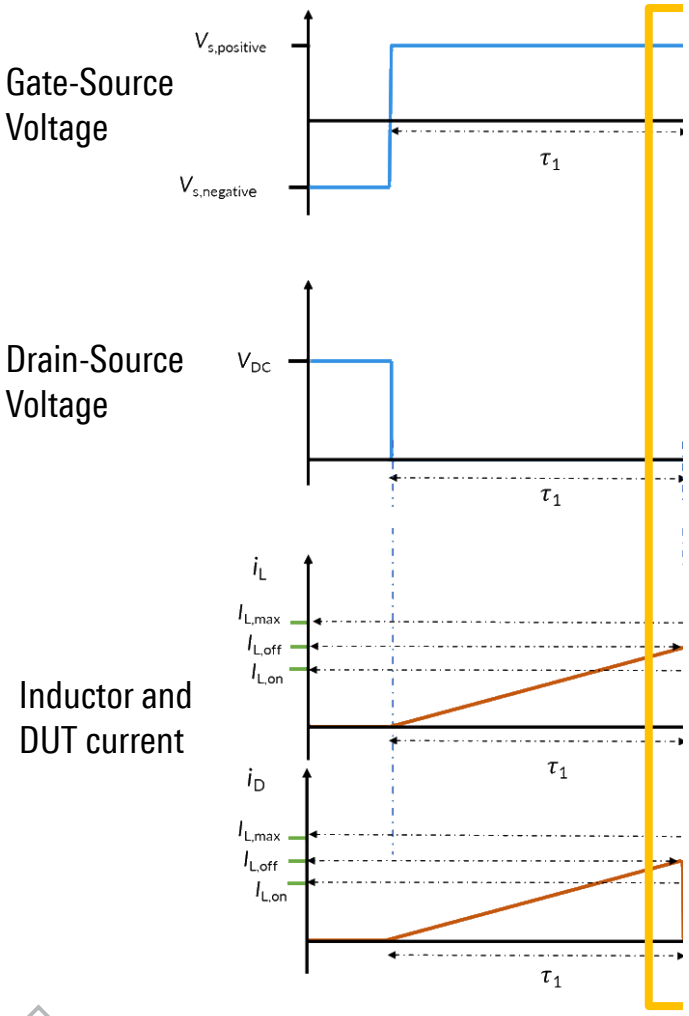
Converter Design

WHY DOUBLE PULSE TESTING 雙脈衝測試主要原因
EXAMPLE: TWO-LEVEL CONVERTER 雙準位轉換器



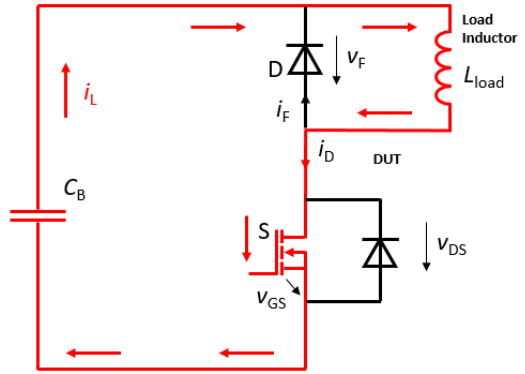
- **A double-pulse test allows to cover all four basic operation modes**
- **All main parameters can be measured**
  - Switching losses 開關損耗
  - Reverse recovery losses 反向恢复损耗
  - Switching times
    - Turn-on/off delay time (TDelay-On/Off)
    - Rise and fall times (TRise, TFall)
    - Speed (di/dt, dv/dt)
    - Switching Energy (E_{ON}, E_{OFF}, E_{RR})

THEORY AND TEST PROCEDURE
原理及測試步驟

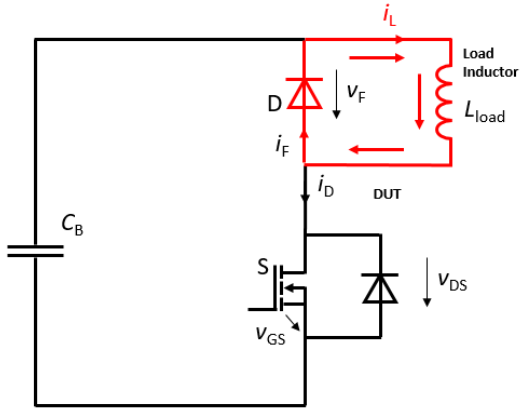


Turn-off Event

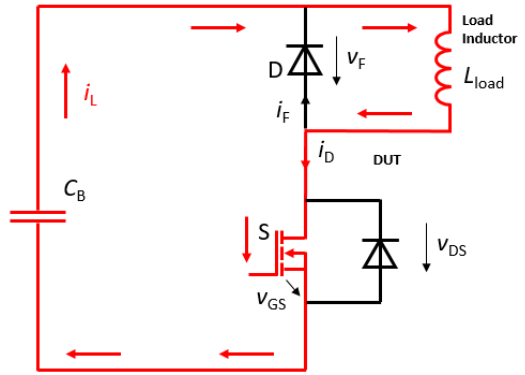
Turn-on Event



Interval τ_1
Inductor is "charged"

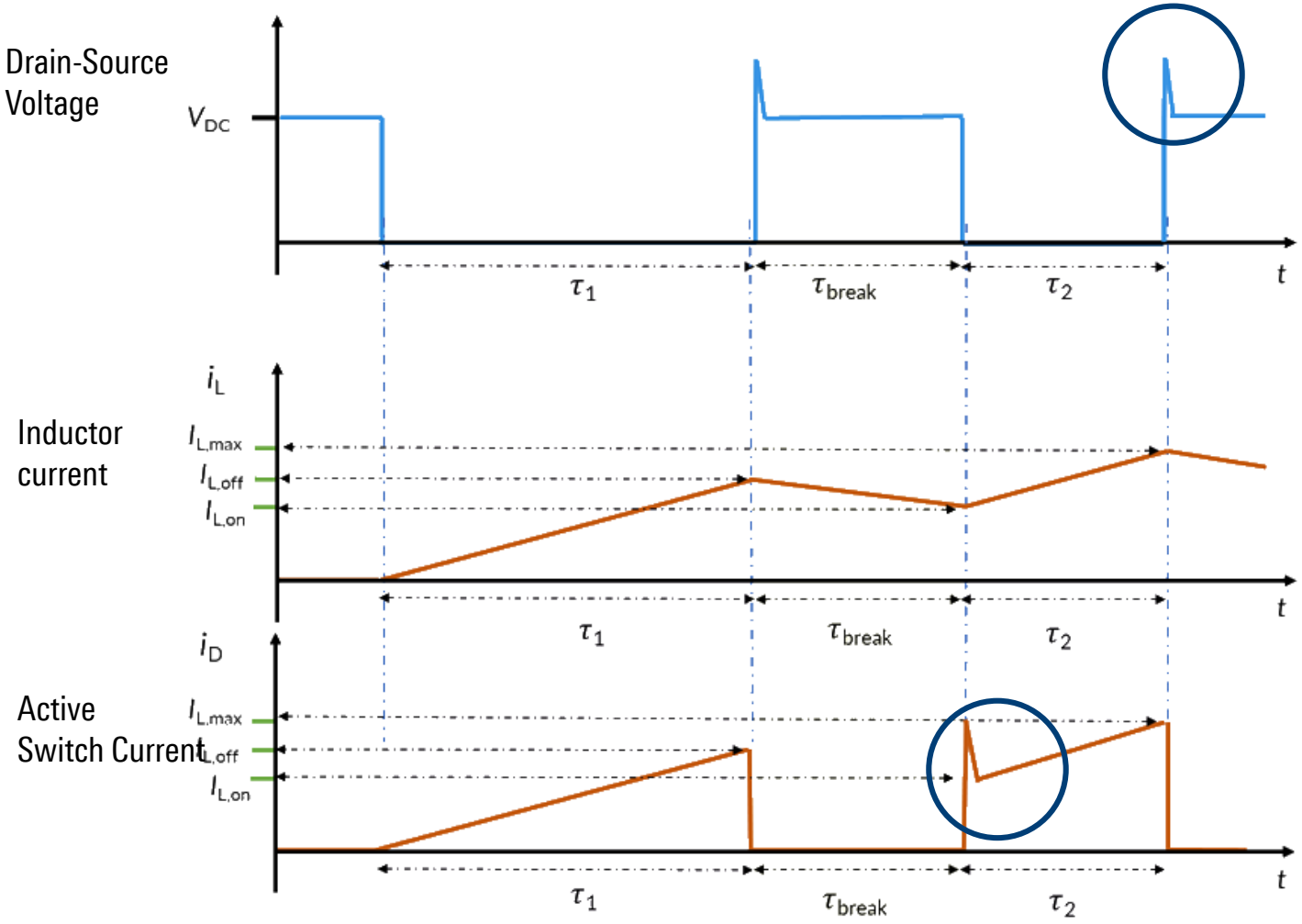


Interval τ_{break}
Turn-off measurement at target current

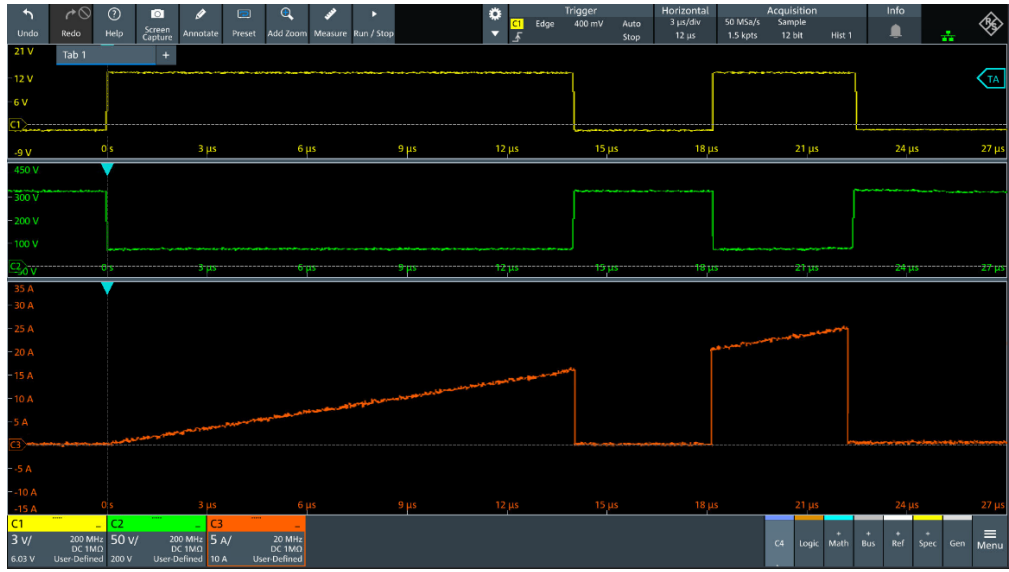


Interval τ_2
Turn-on measurement at target current

BASIC OBSERVATION WAVEFORM
基本實驗波形

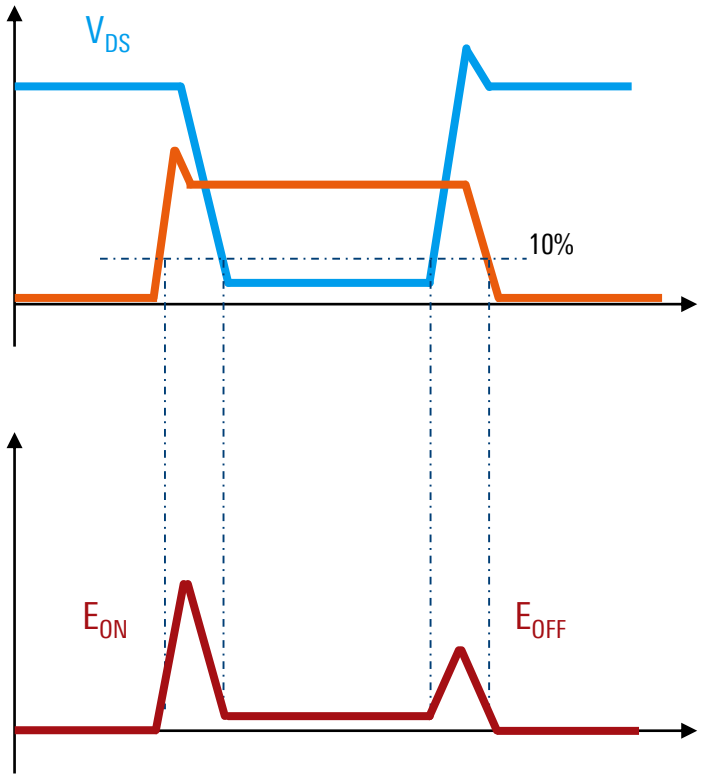


Loop inductances voltage spikes
雜散電感導致的電壓尖峰

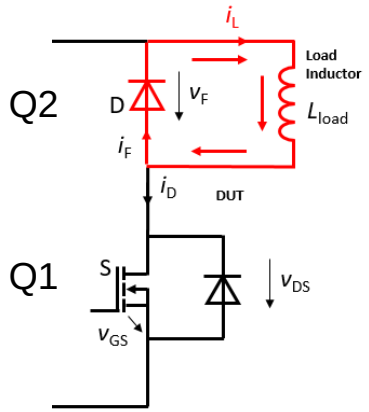


Reverse Recovery Current
反向恢復電流

SWITCHING LOSS MEASUREMENT
開關損耗測量

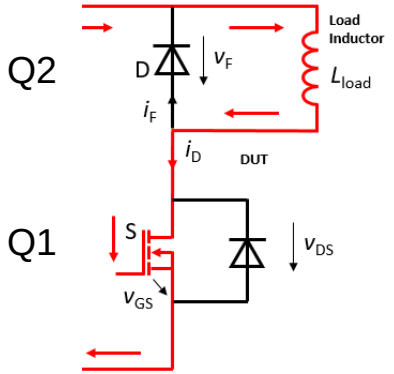


MOSFET Turn-on (E_{ON})

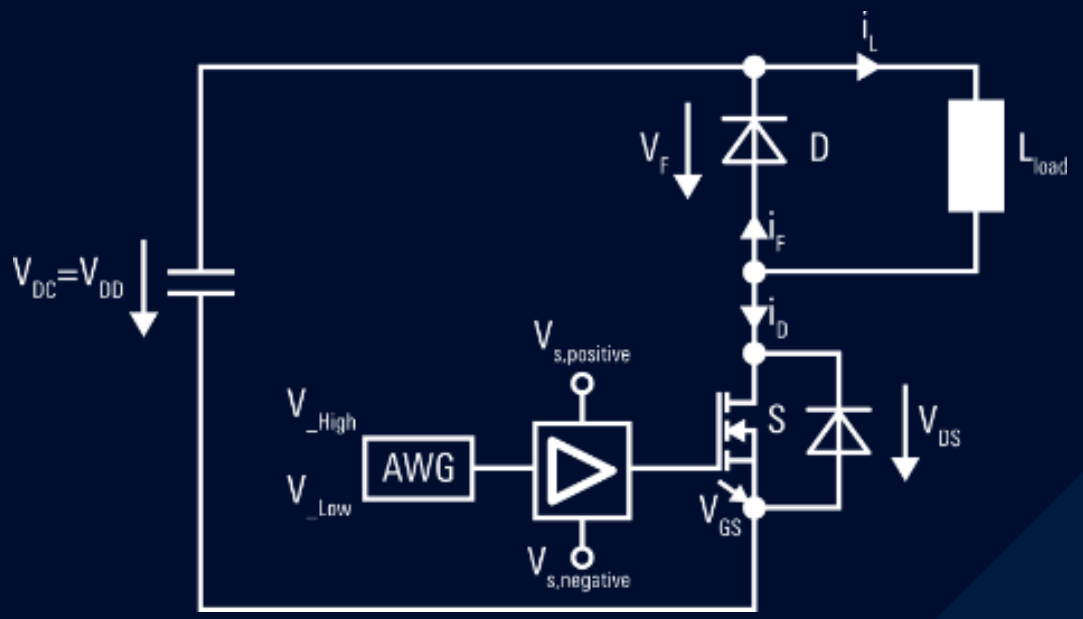


- I_D start to flow through Q2
- V_{DS} remain across Q2 until diode finished conducting
- $P_{ON} = V_{DS} \times I_D$

MOSFET Turn-off (E_{OFF})



- V_{DS} rise across Q2
- I_D remain flowing through Q2 until diode is forward biased
- $P_{OFF} = V_{DS} \times I_D$



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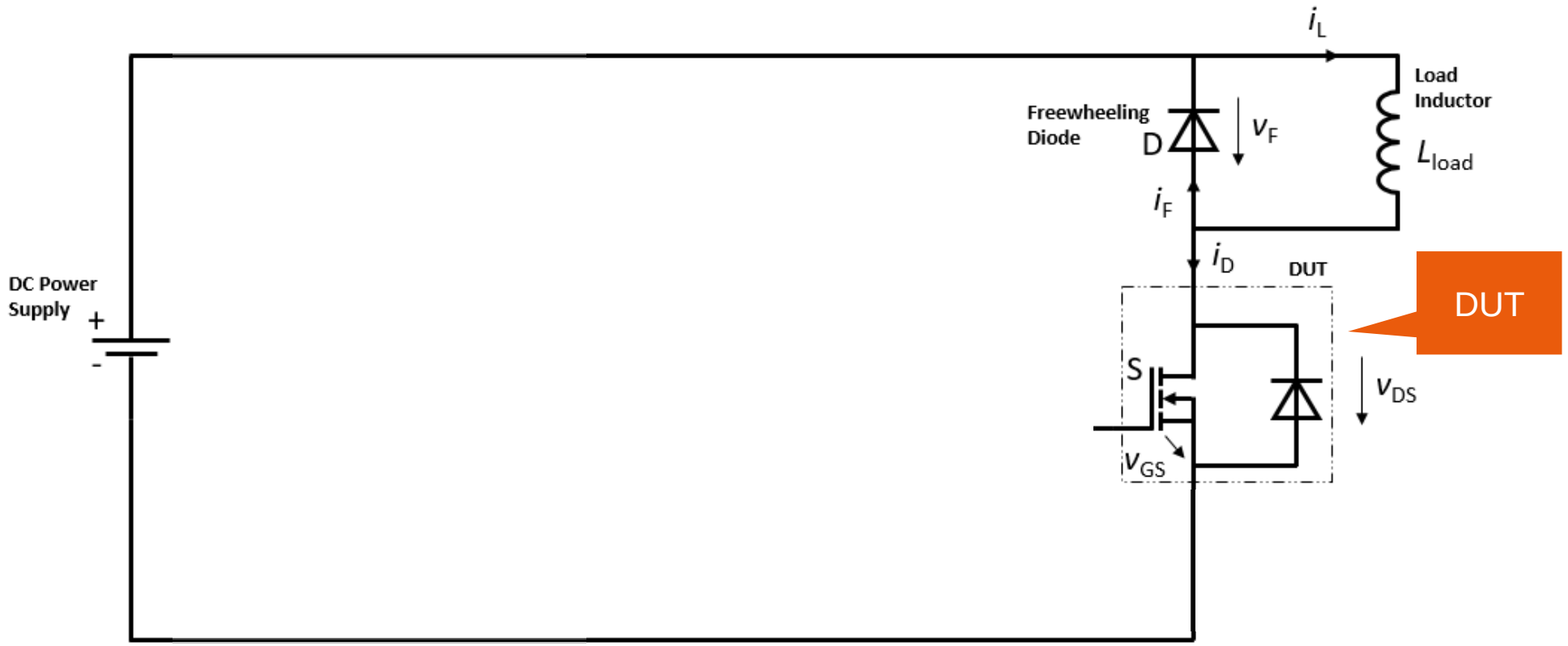
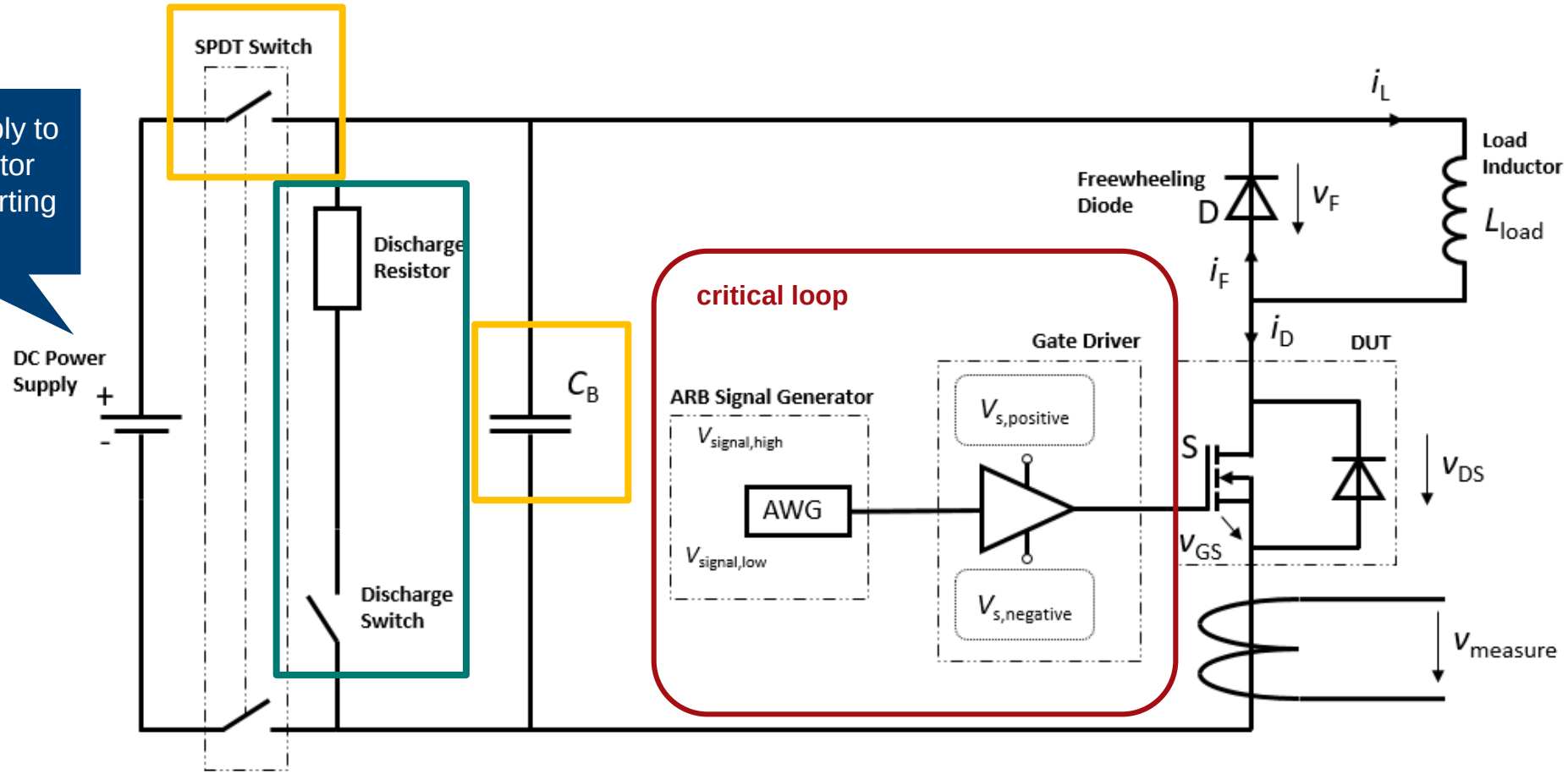
DOUBLE PULSE TEST SETUP
雙脈衝測試設置

TYPICAL SETUP
建立雙脈衝測試平臺



TYPICAL SETUP
建立雙脈衝測試平臺

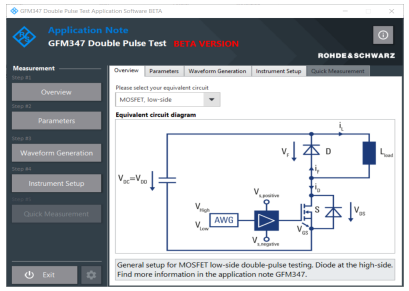
DC Power Supply to charge capacitor bank before starting the test



INSTRUMENT INVOLVED
相關儀器

HMF2550 ARB Generator

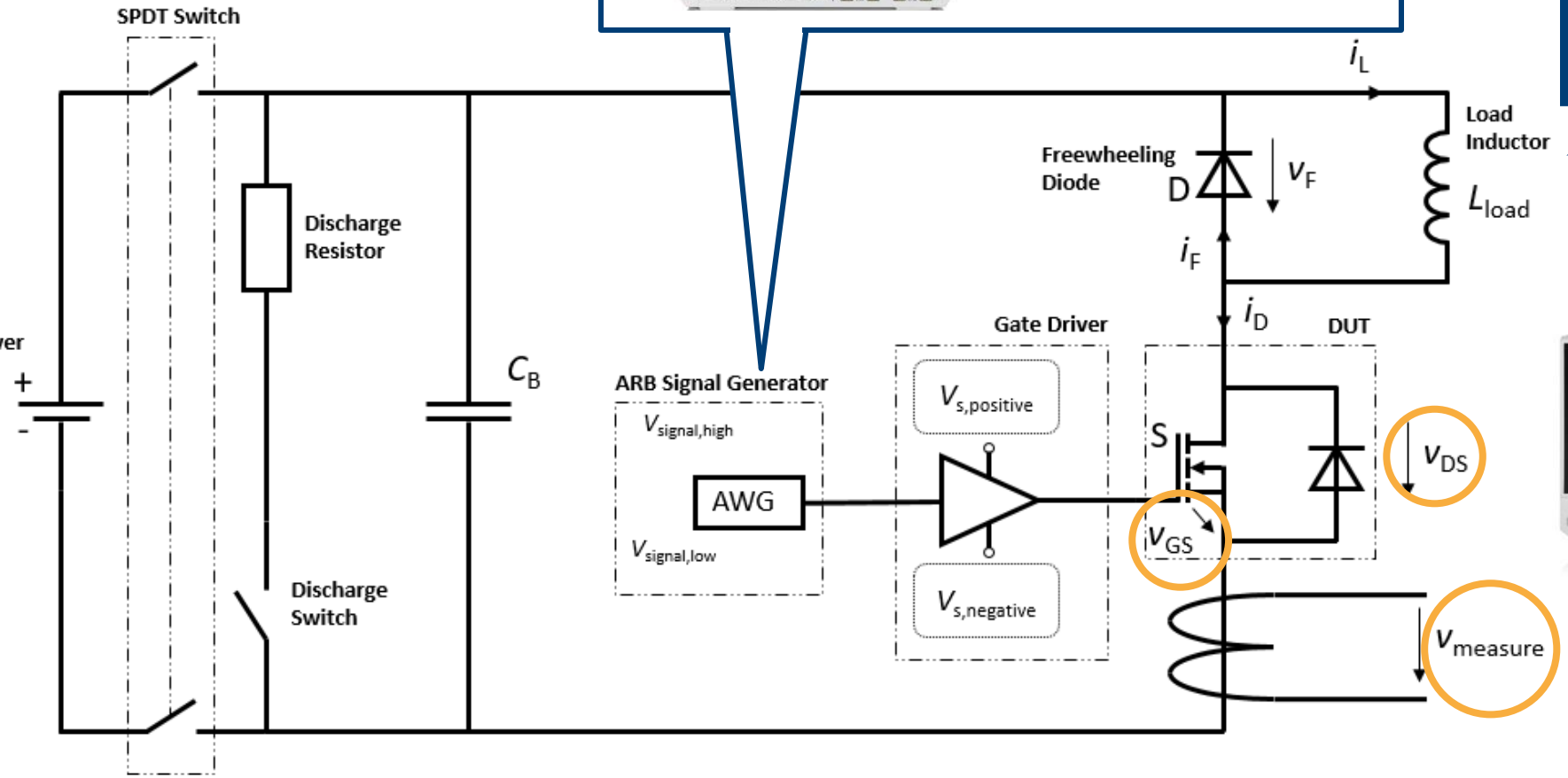
DBT SW



RTM3000 Oscilloscope

DC Power Supply to charge capacitor bank before starting the test

Floating output important!

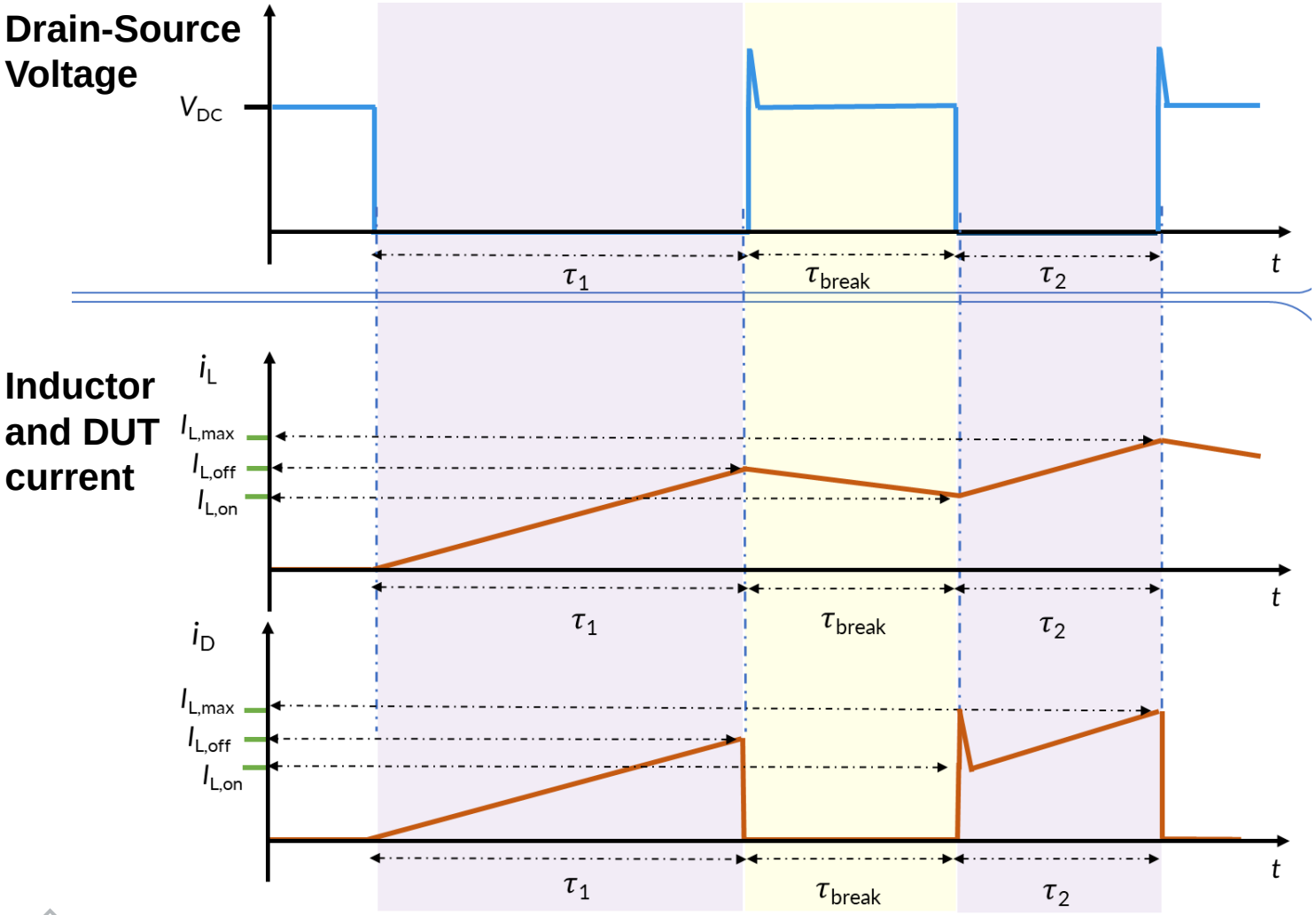


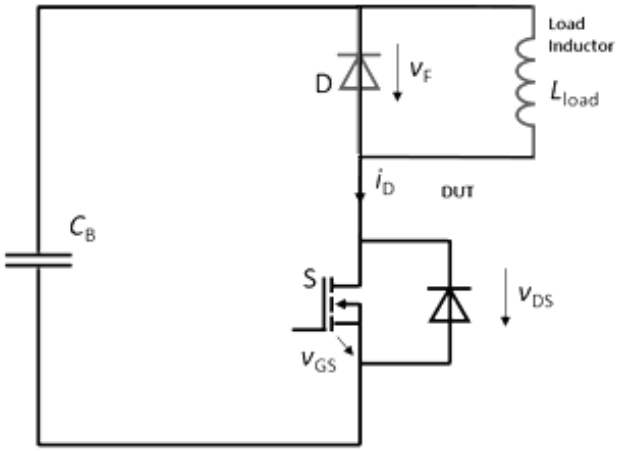
Load inductor, “stores” current for the actual test

MXO 4 Oscilloscope

RTM3000 Oscilloscope

SETTING UP THE PULSE
建立雙脈衝波形的特性





$$\tau_1 = L_{LOAD} * \frac{i_L}{V_{DC}}$$

τ_{break} is set long enough for the voltage and currents to settle out

τ_2 usually short enough not to exceed the reverse bias SOA

$\tau_1 + \tau_2$ should not be too large to create self heating of the DUT

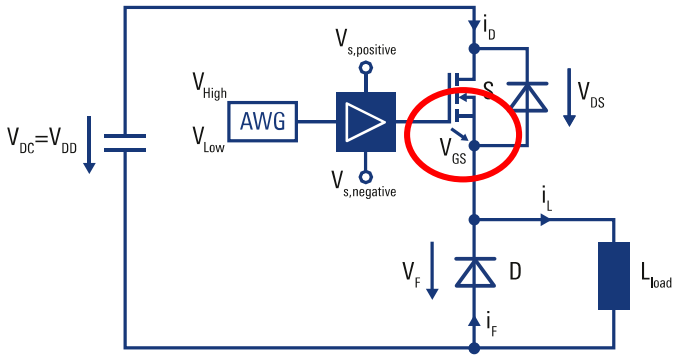
SETTING UP THE MEASUREMENT
測量搭配 – 電壓探棒篇

- **Passive probes are sufficient for floating setups**
  - Typically possible for device characterization setups
  - Care has to be taken on any (unintentional) grounding

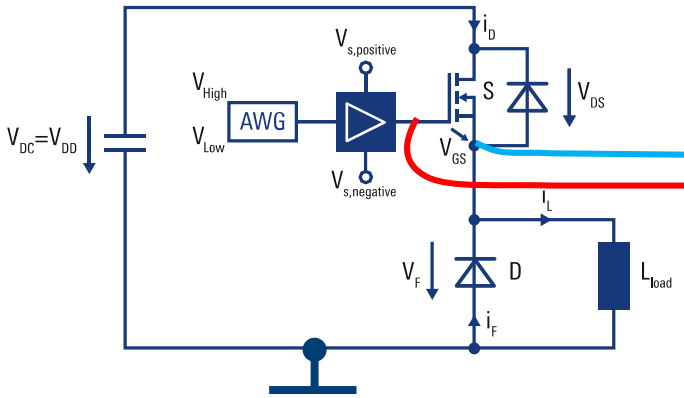
- **Broadband differential probes are an attractive alternative for floating setups**
  - Very high bandwidth of up to 1 or 2 GHz
  - Very low loading (~ 1pF)
  - Input voltage range of +/-50V DC with 10:1 attenuator

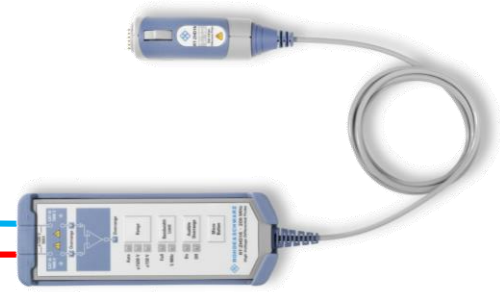
- **High-voltage differential probes are necessary if system-under-test is grounded**
  - Typically the case for prototypes
  - Provide CMRR to suppress switch-node signal

Floating High-side DUT



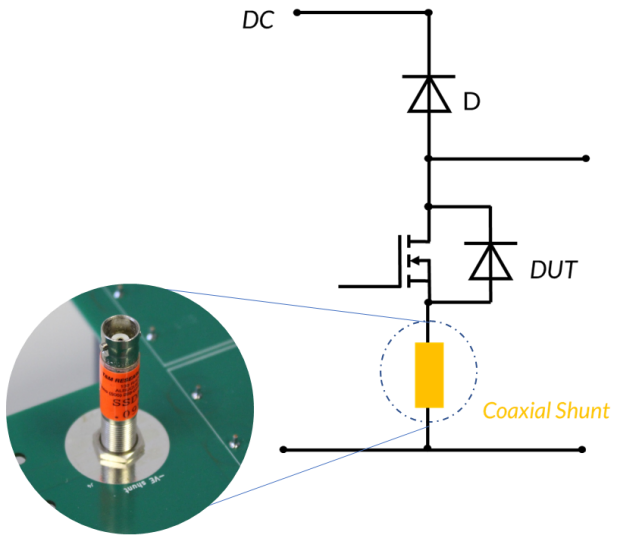
Grounded High-side DUT

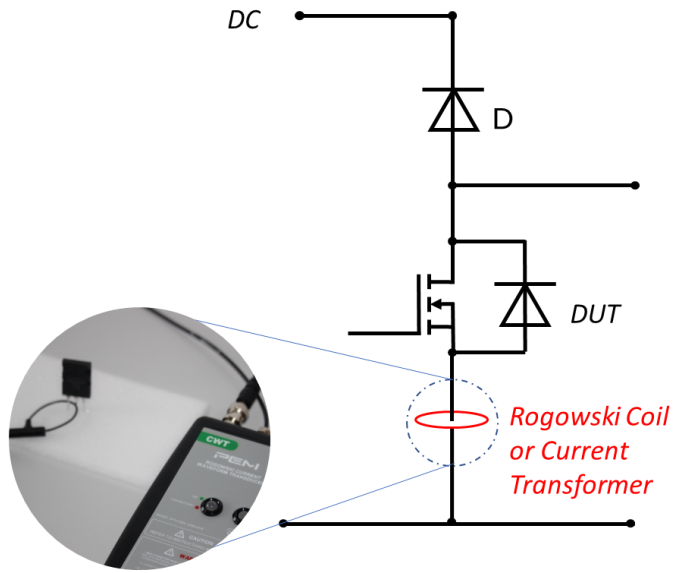




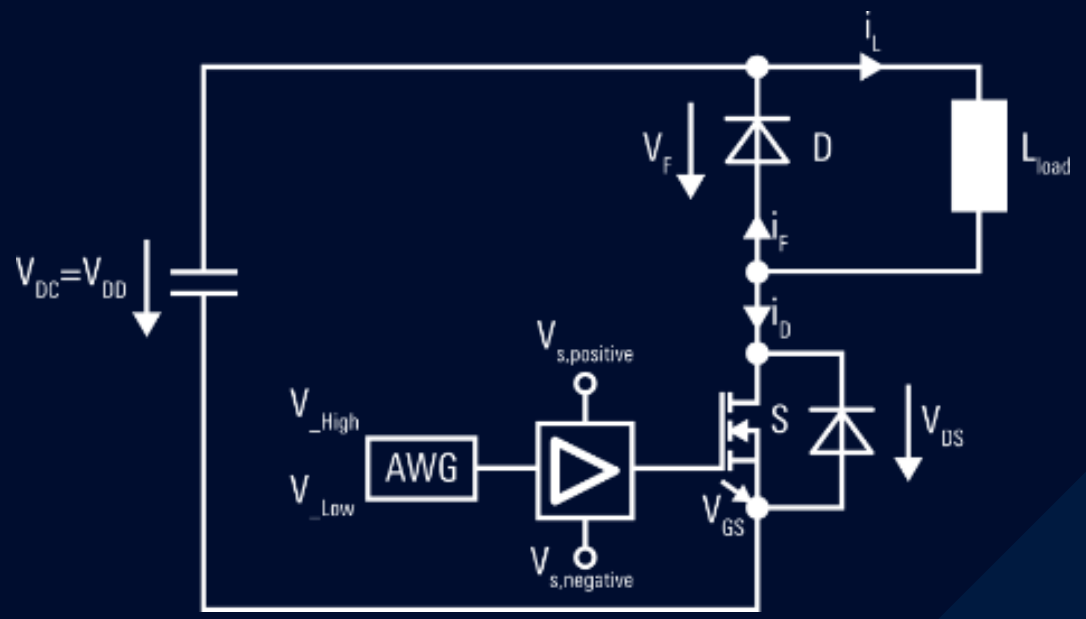
SETTING UP THE MEASUREMENT
測量搭配 – 電流探棒篇

- **Basic requirements**
  - High measurement bandwidth
  - Sensor as small as possible
  - Low insertion inductance





	Coaxial shunt	Rogowski probe	Current transformer
Pro's	• Very high bandwidth (2 GHz) • DC-measurement capability • Very low insertion inductance	• Physically small, no "design-in" of sensor necessary	• High bandwidth (~200 MHz) • High current possible
Con's	• Limited maximum current • Design-in of sensor necessary	• Limited bandwidth (typically 30-50 MHz but recently also higher bandwidth up to 100 MHz available) • Limited accuracy	• Design-in of sensor necessary • Large sensor with core, limits the possibility to have low-insertion inductance designs



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TODAY'S OSCILLOSCOPE
示波器新功能

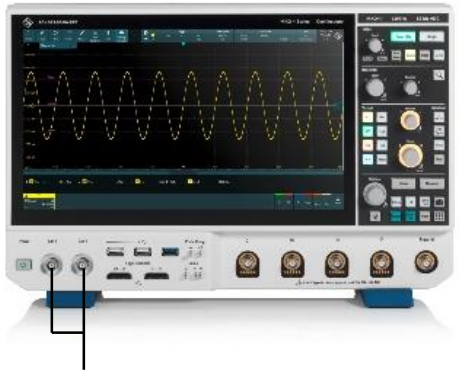
SIGNAL AND ARB GENERATOR
信號和任意波形產生器

► Signal generator has becoming a norm in basic scope model

RTM/RTA

Single channel

MXO 4



Dual channel

RTO6

At the back

Dual channel

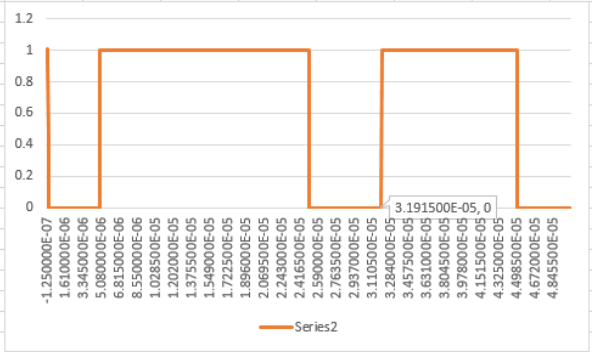
► Most scopes are equipped with:

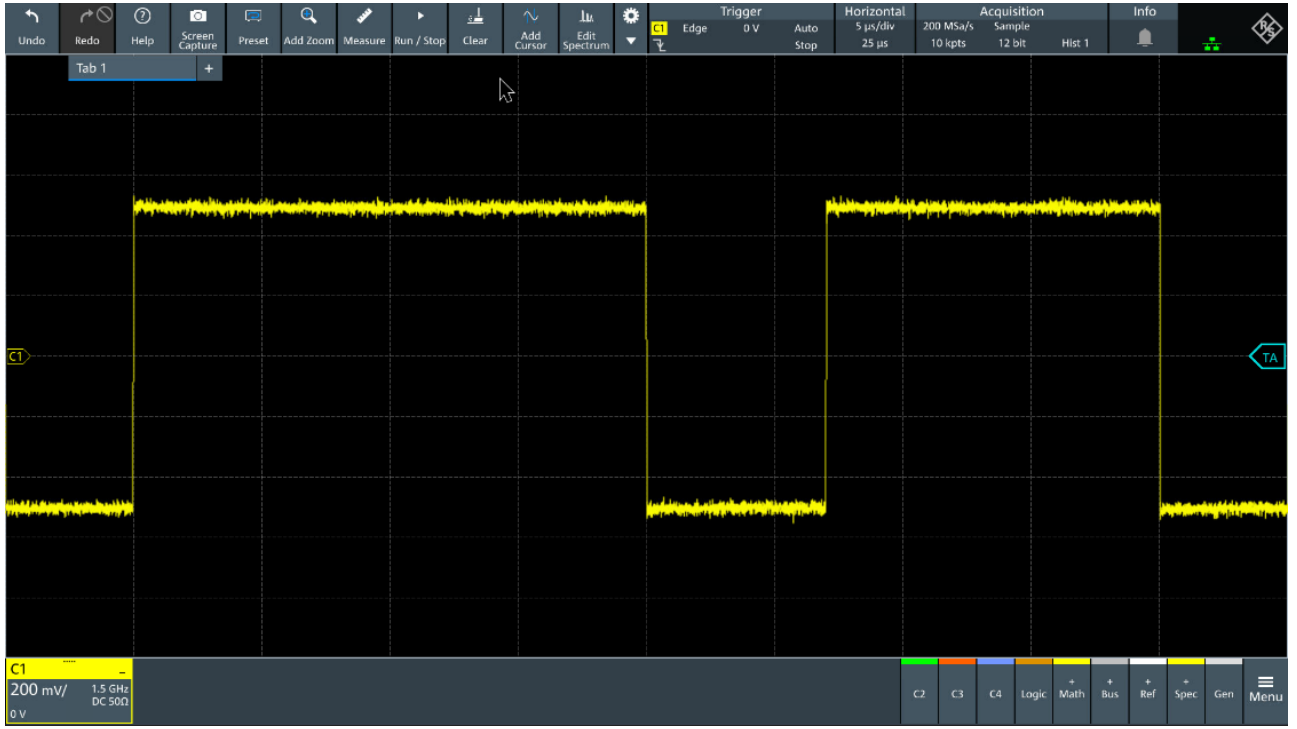
– Function generator: Predefined waveform shapes with configurable frequency & amplitude

– Arbitrary generator: Generate any waveform shapes based on generator sampling rate

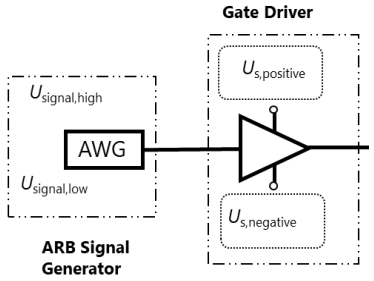
SIMPLE EDITING VIA EXCEL
簡單編輯

	A	B	C	D	E	F	G	H	I	J	K
28	InterpolationMode	SIN_X_DIV_X									
29	CenterFreq	500									
30	FreqSpan	1000									
31	ResolutionBW	1									
32	FrequencyStart	0									
33	FrequencyStop	0									
34	WindowType	GAUSSIAN									
35	GateRBWCoupling	KEEP_GATE									
36	HorizontalDivisionC	10									
37	VerticalDivisionCou	10									
38	FirmwareVersion	1.2.3.2									
39	XAxisMode	LINEAR									
40											
41											
42											
43	TIME	C1									
44	-1.250000E-07	0.978256									
45	-1.200000E-07	0.999756									
46	-1.150000E-07	0.991937									
47	-1.100000E-07	1.005619									
48	-1.050000E-07	0.976301									
49	-1.000000E-07	0.99096									
50	-9.500000E-08	0.991937									
51	-9.000000E-08	0.993892									
52	-8.500000E-08	0.986074									
53	-8.000000E-08	1.007574									
54	-7.500000E-08	0.986074									
55	-7.000000E-08	0.995847									
56	-6.500000E-08	0.998778									
57	-6.000000E-08	0.986074									
58	-5.500000E-08	0.984119									
59	-5.000000E-08	0.978256									
60	-4.500000E-08	0.983142									
61	-4.000000E-08	0.98021									

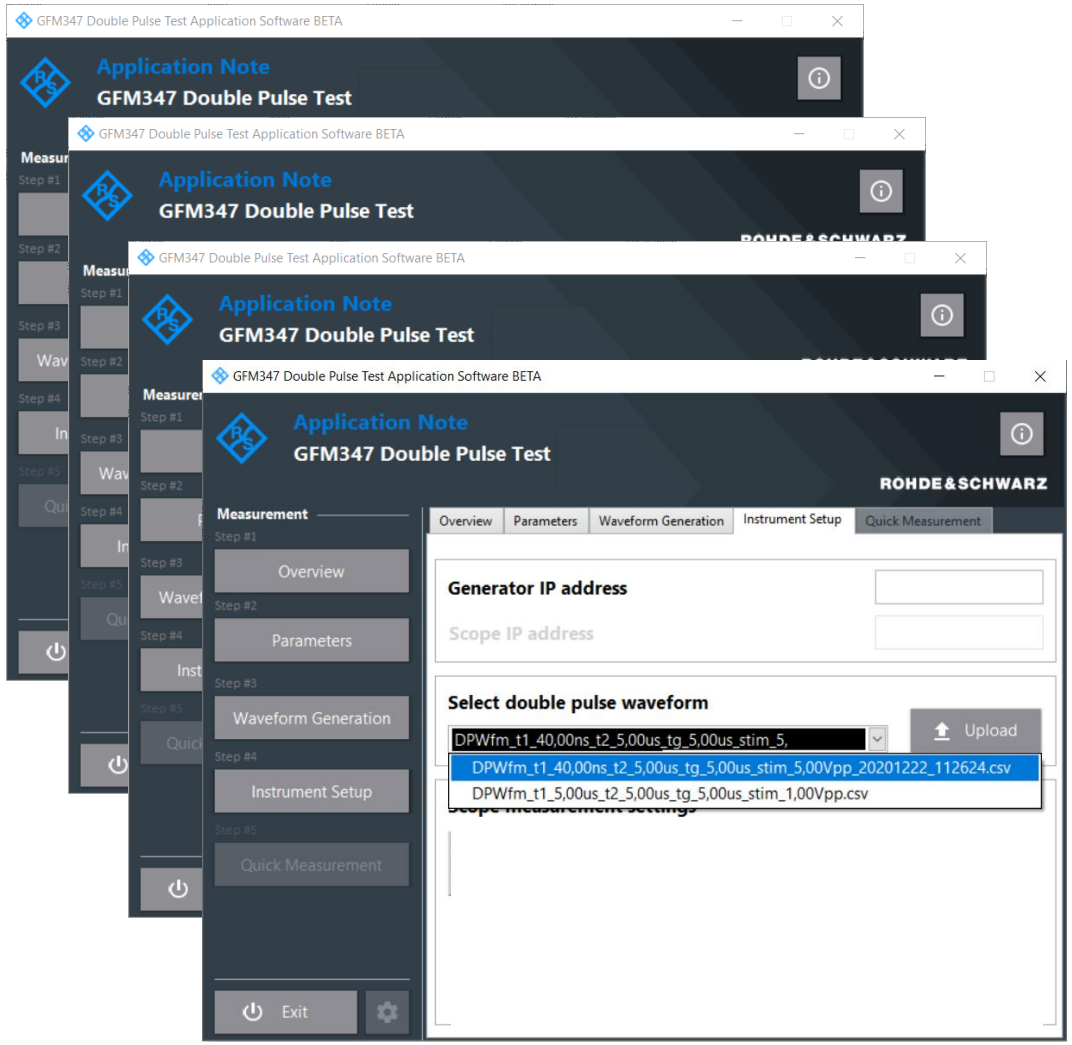




SETTING UP THE ARB WITH APP
建立任意波形軟體



- **Important considerations**
  - Clean turn-on procedure without any spikes
  - Right signal levels
- **Double pulse test App**
  - Create ARB waveform based on test parameters
  - Recall ARB waveforms using descriptive names
  - Directly upload to external ARB or oscilloscope
- **Tips:** Always check ARB signal when creating new setup



INDUSTRY'S FIRST…
業界領先…

>4.5 Million wfms / sec

12 -bit ADC 18-bit HD

400 Mpts memory /ch

Digital trigger

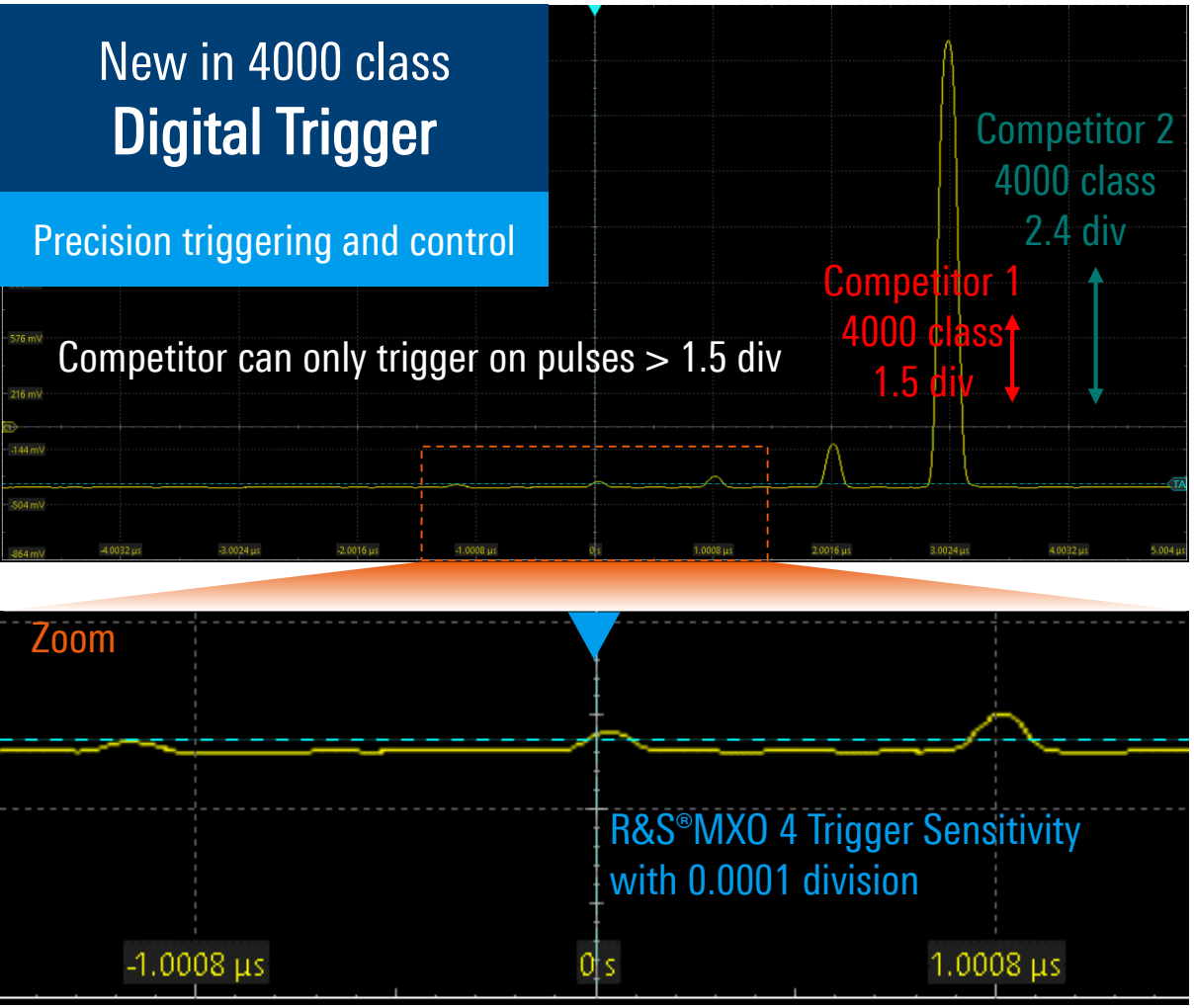
2x ARB Gen 100 MHz

Standardized MSO 16ch 5GSa/s

ISOLATE EVENTS WITH MORE PRECISION
更精確地隔離觸發

New in 4000 class
Digital Trigger

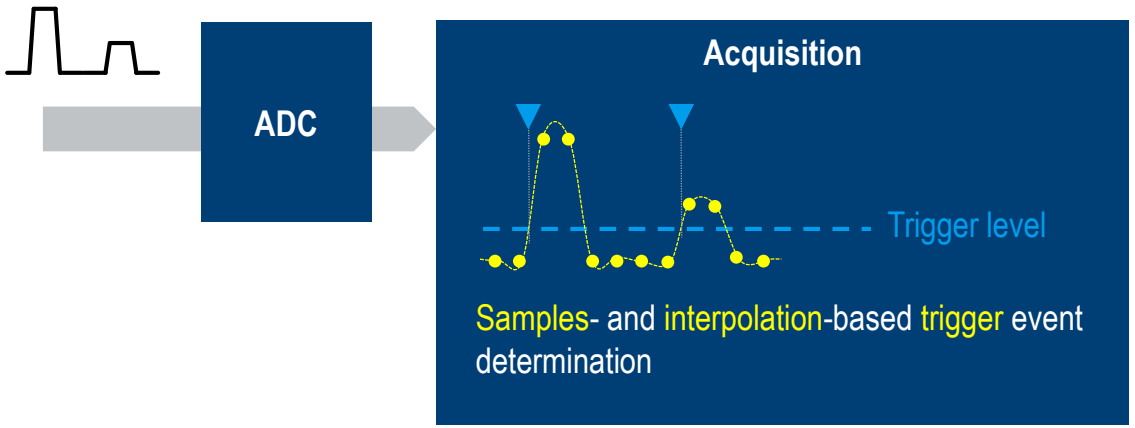
Precision triggering and control



R&S®MXO 4 features

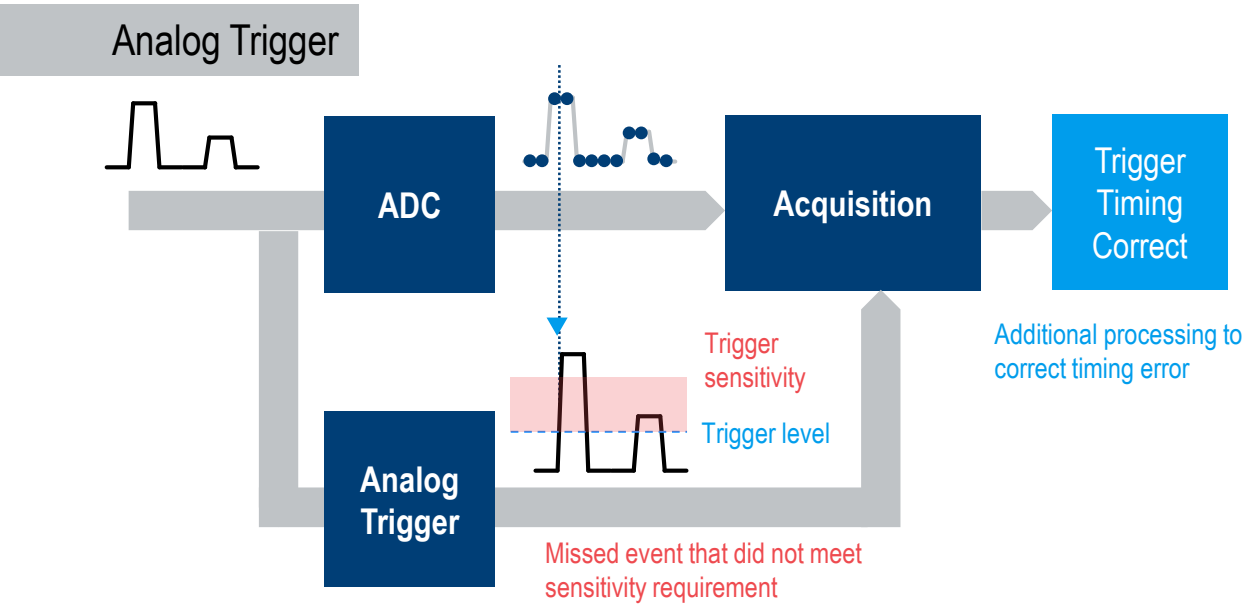
- ▶ Detect trigger event on sampled waveforms
- ▶ Adjustable trigger sensitivity
- ▶ Minimal trigger jitter < 1ps
- ▶ 18 bit architecture

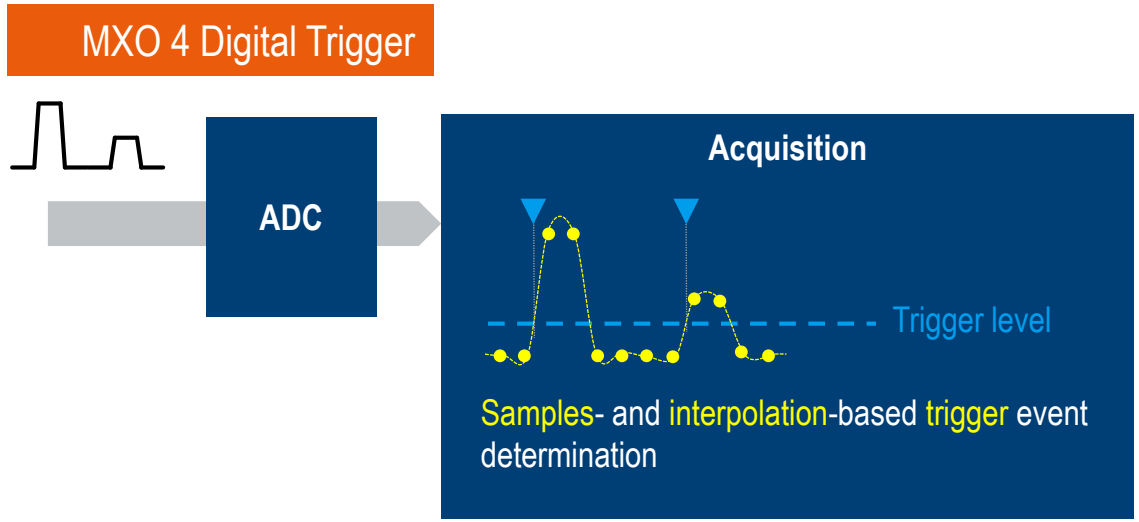
MXO 4 Digital Trigger



HIGH PRECISION DIGITAL TRIGGER
高精度數位觸發

► In most 4000 class oscilloscope, limited processing power often use analog trigger

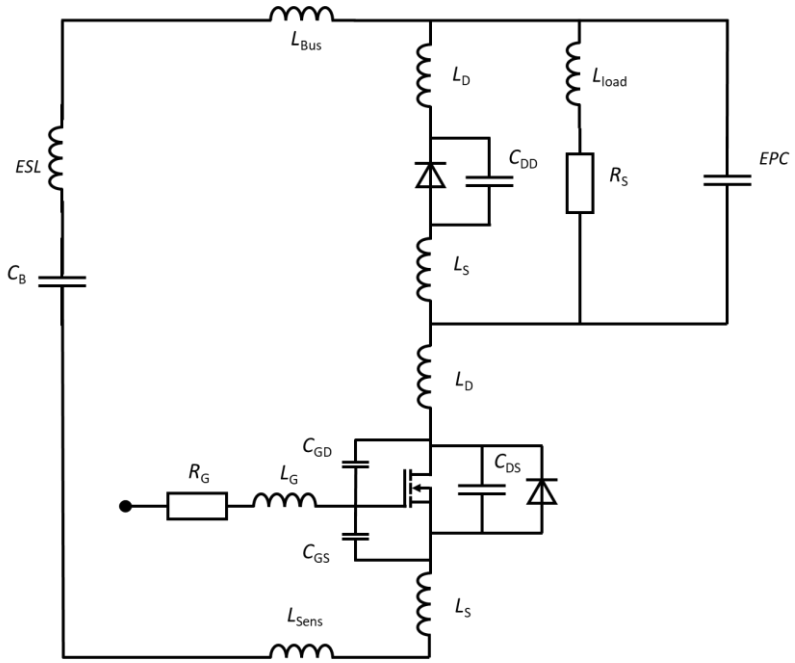




Limitation:
► Lower trigger sensitivity, more than 0.5 div
► Timing alignment between trigger and acquisition block

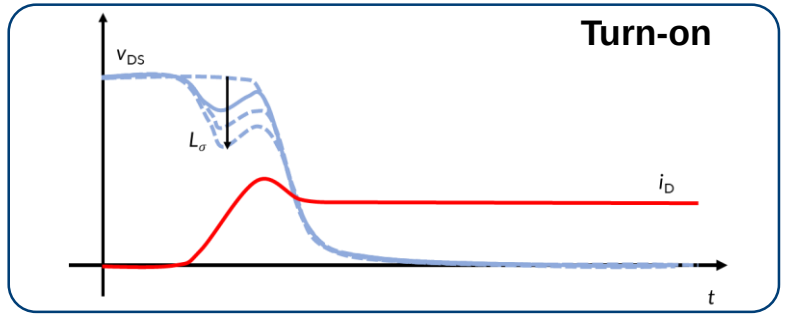
Advantages:
► Trigger sensitivity > ADC resolution
► Essentially no trigger jitter

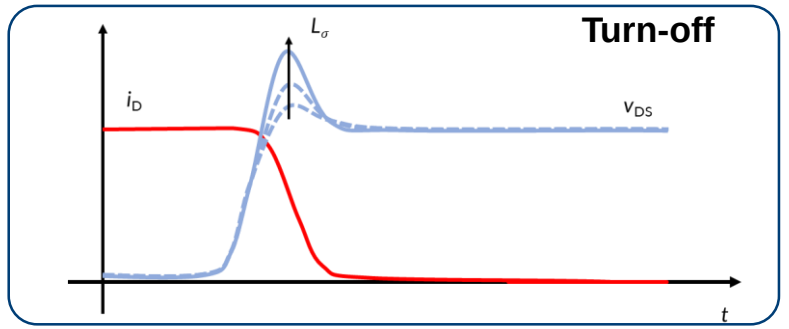
THE EFFECTS OF PARASITICS
散雜電容電感的影響



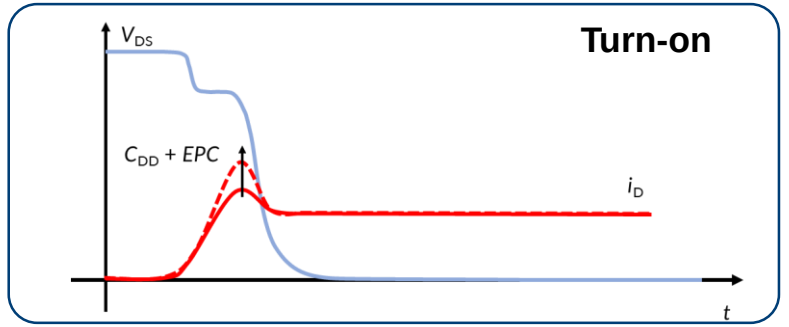
- Parasitic components cause voltage spikes and ringing, EMI interference and reliability problems
- Parasitics in application do not match with datasheet setup
  → device losses differ additional testing required
- Stray inductance of utmost importance

Impact of stray inductance L_σ

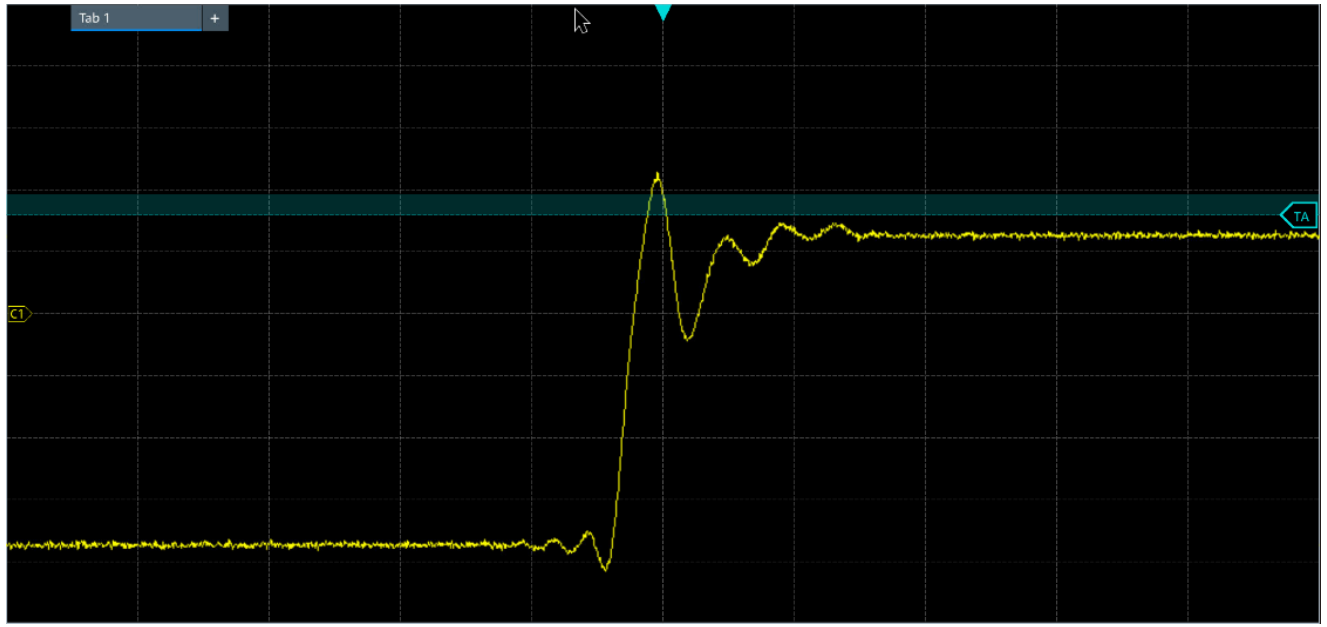




Impact of stored charge C_{DD}+EPC



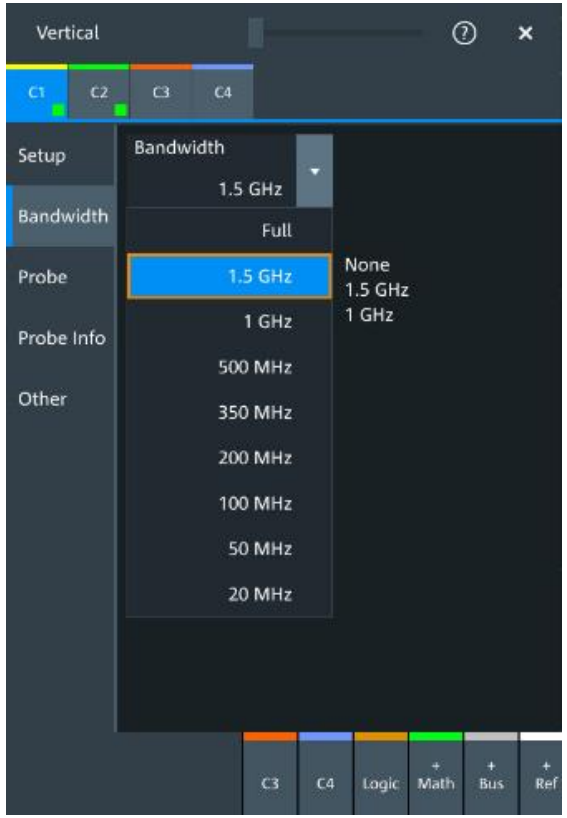
TRIGGERING SWITCHING EDGES
觸發開關邊緣



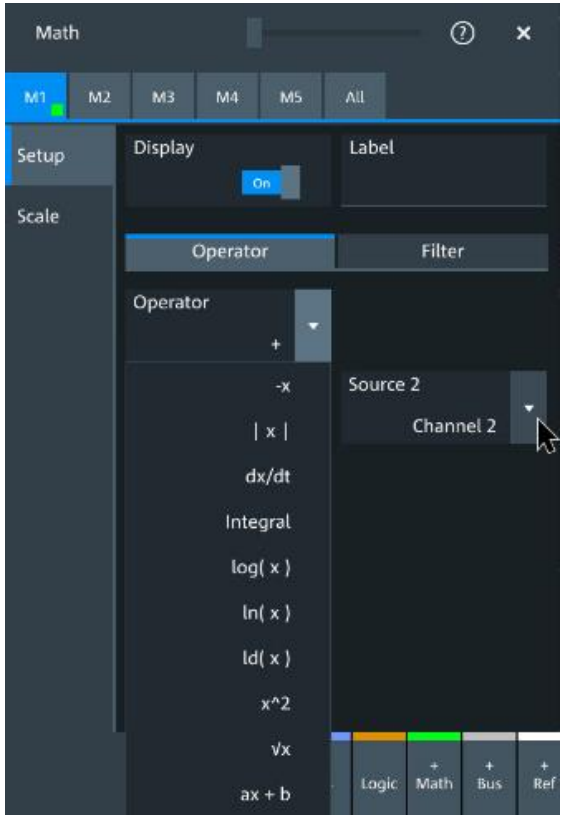
- Parasitic and Miller effects will cause irregular waveforms noises especially around Turn-On and Turn-Off.
- Digital trigger allows settings of a signal levels require that help to filter off ringing noises

ADVANCE TOOLS IN MODERN OSCILLOSCOPE
现代示波器中的先进工具

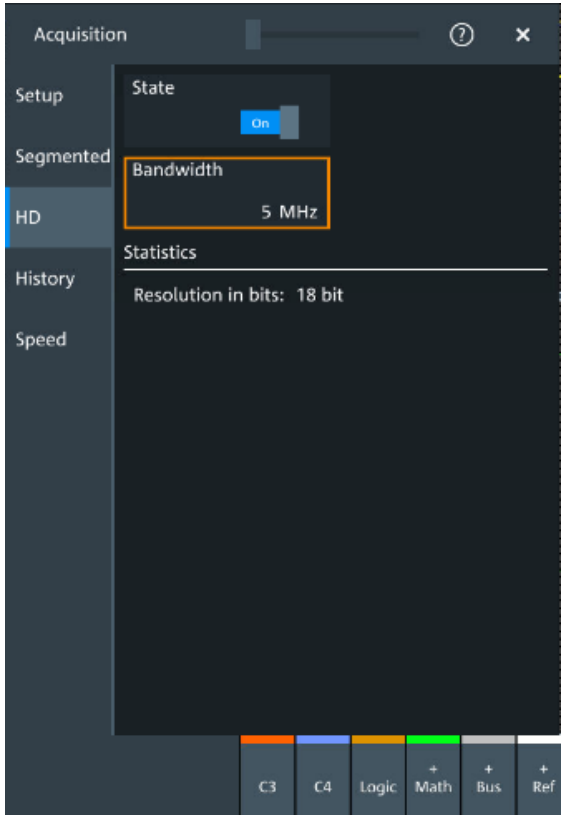
Bandwidth Filtering



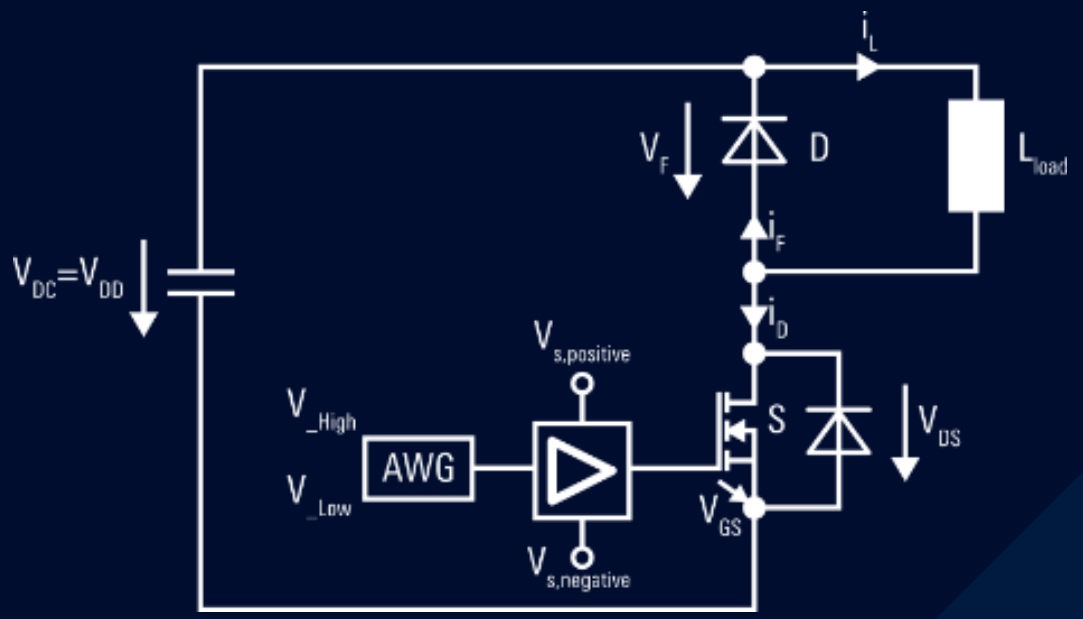
Advance Math



HD Mode



… and a lot more



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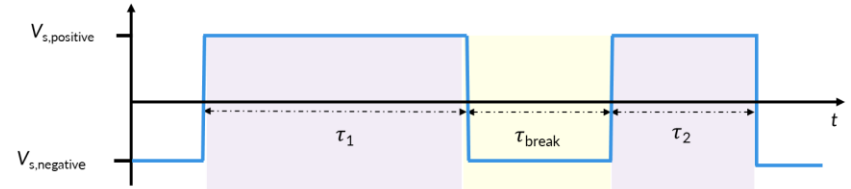
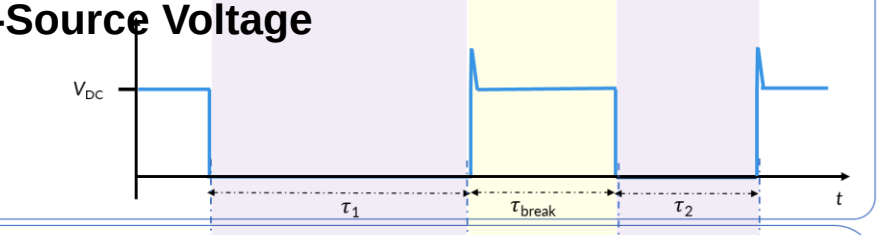
EXAMPLE OF MEASUREMENTS
測量範例

A PRACTICAL EXAMPLE 實測案列
650V 4-PIN TO-247 SIC MOSFET (ROHM), 400V DC LINK

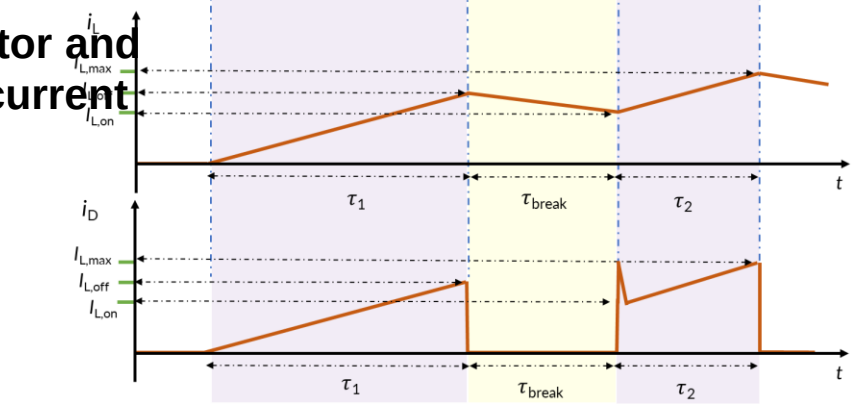
Gate-Source Voltage

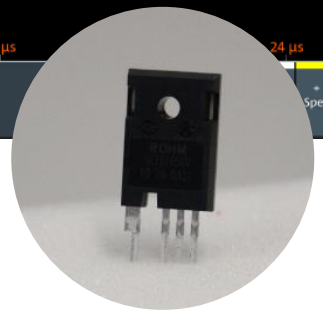


Drain-Source Voltage



Inductor and DUT current

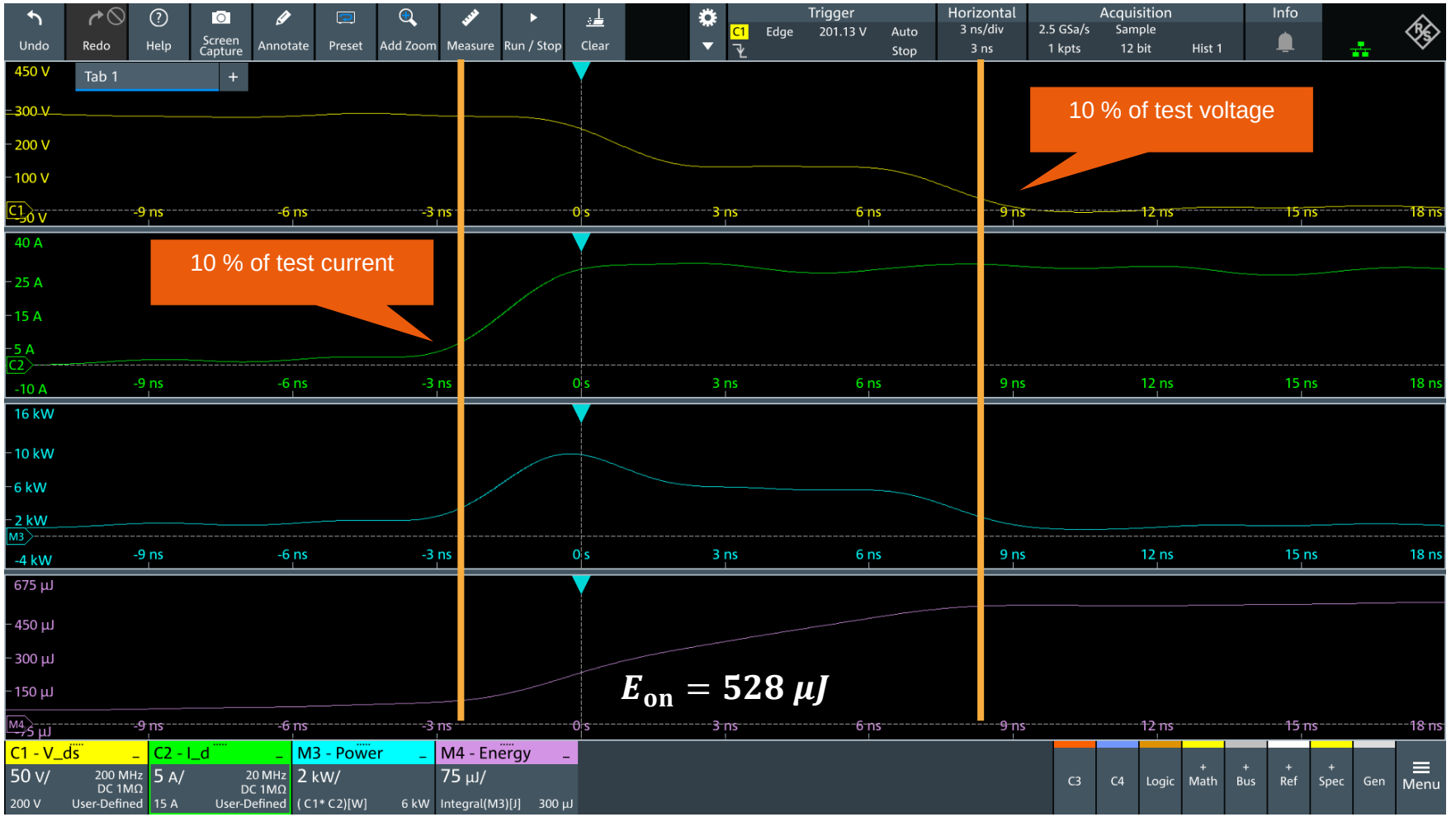




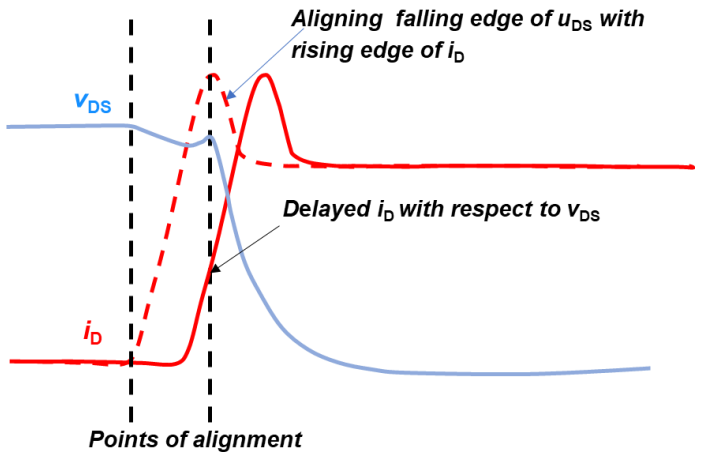
A PRACTICAL EXAMPLE 實測案列
TURN-ON ENERGY 打開功率

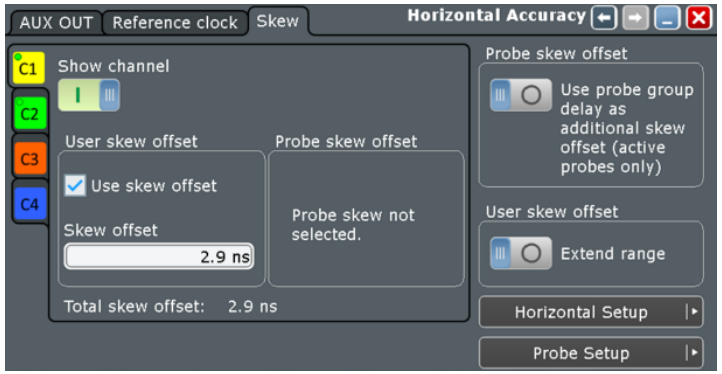
$$P_{\text{turn-on}} = v_{\text{DS}}(t) \cdot i_{\text{D}}(t)$$

$$E_{\text{on}} = \int_{t_{\text{I}_{\text{test10}}}}^{t_{\text{V}_{\text{DC10}}}} P_{\text{turn-on}}\ dt$$



PRACTICAL EXAMPLE 實測案列
DE-SKEW 相位校正





CONCLUSIONS 總結

- Double pulse test is simple in concept but there are many underlying factors that can impact measurement accuracy
  - DUT setup parasitic
  - Instruments artefacts
  - Basic compensation and deskewing

- Newer scopes are built with advance tools that help in tackling the above
  - Built in ARB with simple editing
  - Digital trigger with precision
  - Advance Math and Measurement capabilities

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THANK YOU
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