示波器在无线和射频测试中的应用

Apr. 2015

李凯

KEYSIGHT TECHNOLOGIES

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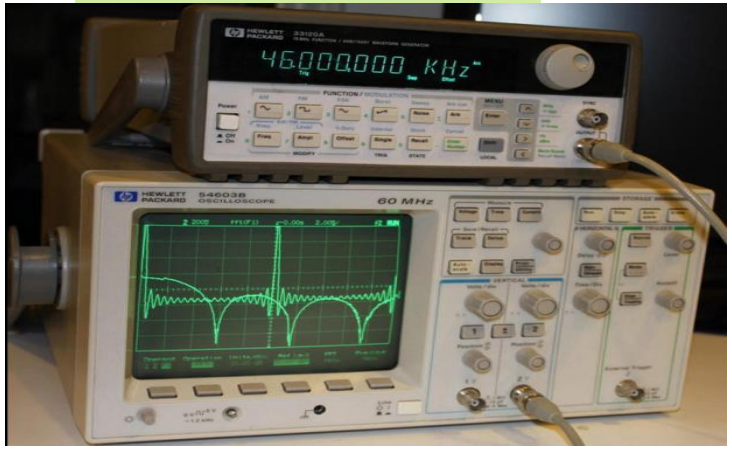
KEYSIGHT TECHNOLOGIES

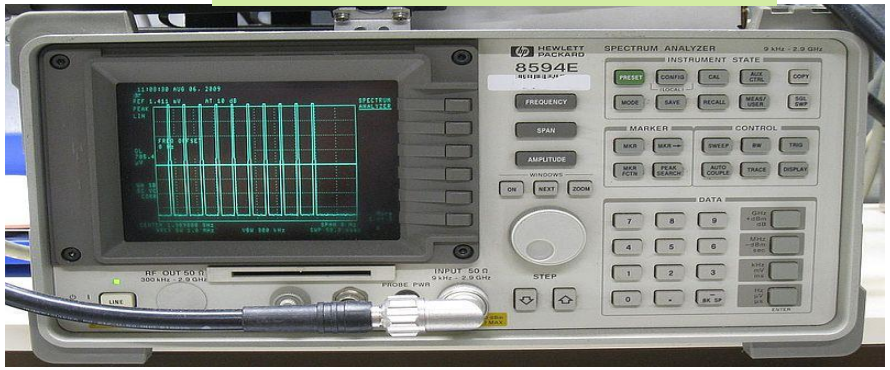
传统的测量仪表

- 以特定功能的硬件为主体
- 用按键和旋钮进行控制
- 通过简单的数码或图形界面显示基本参数的测试结果
- 简单的互联和数据传输能力

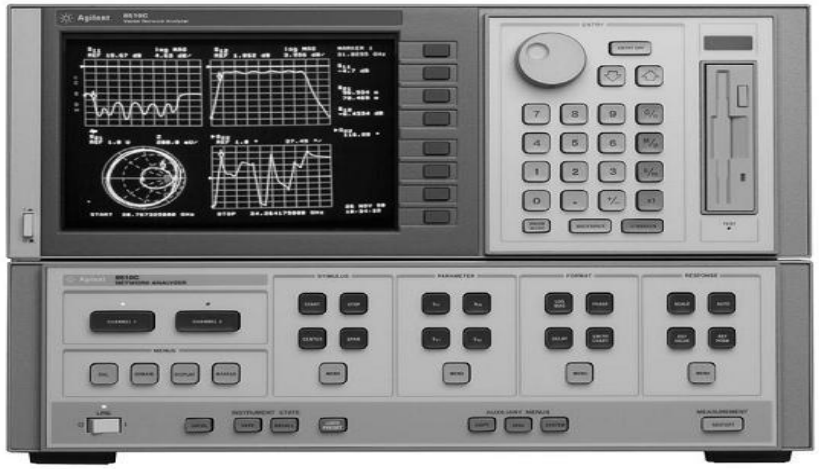
54603B示波器



8594E频谱分析仪



8510矢量网络分析仪



8656B信号发生器

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现代的测量仪表

- 硬件和软件分析功能融合
- 借助软件进行硬件特性修正或数据处理
- 强大的信号分析功能
- 强大的互联和数据传输能力

34461A 数字万用表

UXA 频谱分析仪

PNA-X矢量网络分析仪

6000X
示波器

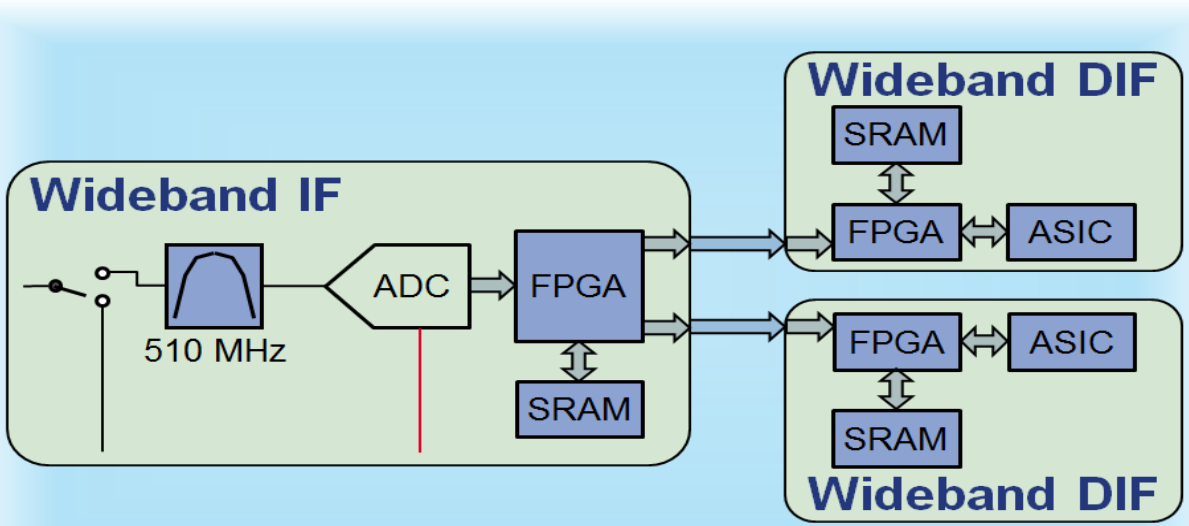
KEYSIGHT TECHNOLOGIES

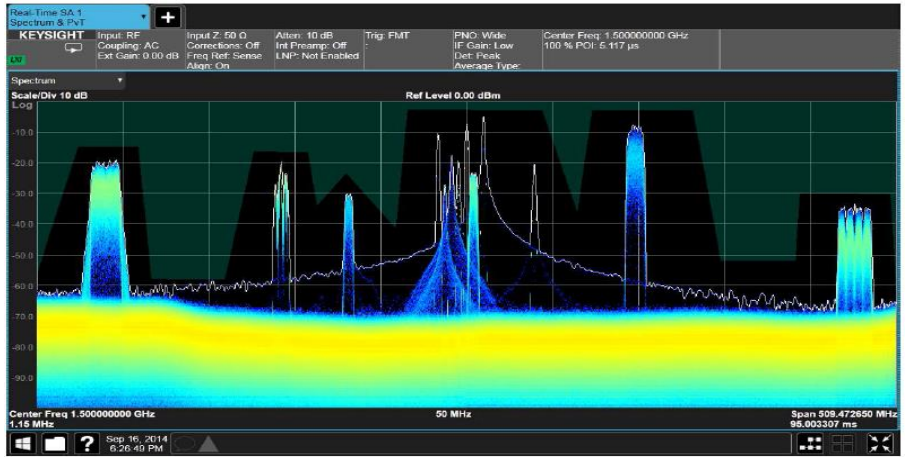
高速芯片和信号处理技术在仪表中的应用

提升频谱仪的实时分析带宽

- Utilizes MRL Designed ADC (2.4 Gsa/sec clock rate)
  - Virtex 6 FPGA provides post-processing of the ADC data
  - Supports either 255 MHz Bandwidth (B2X) or 510 MHz Bandwidth (B5X)

IF Signal

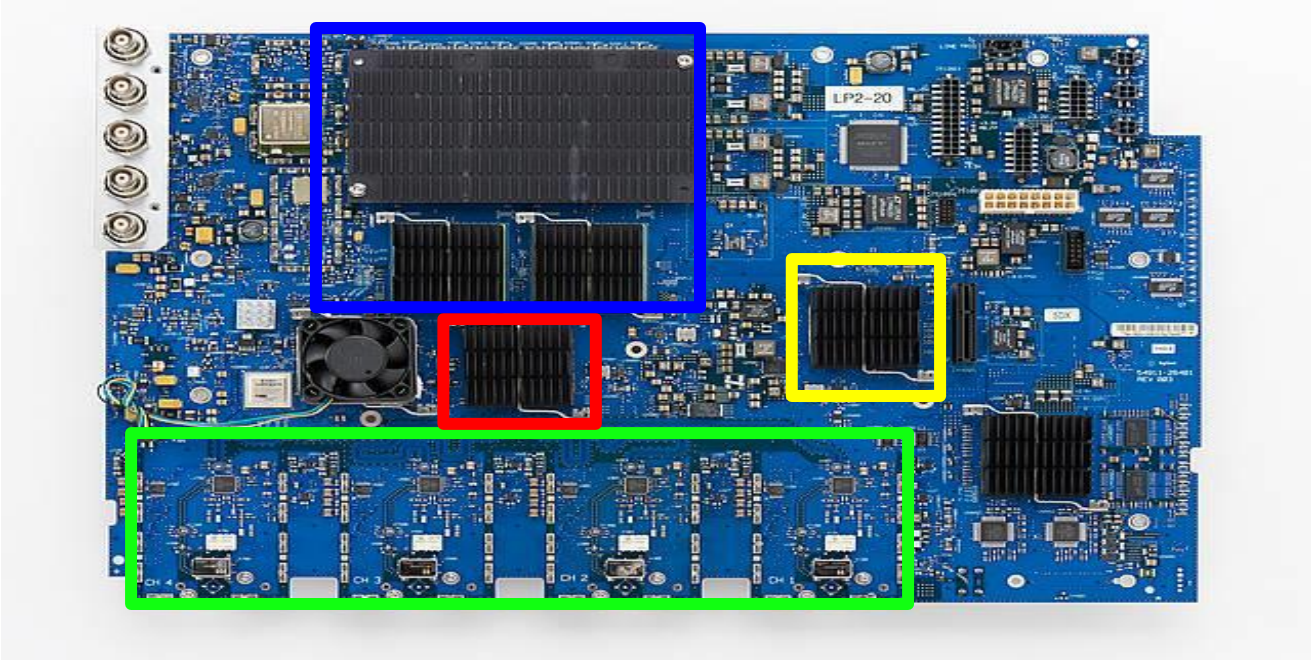


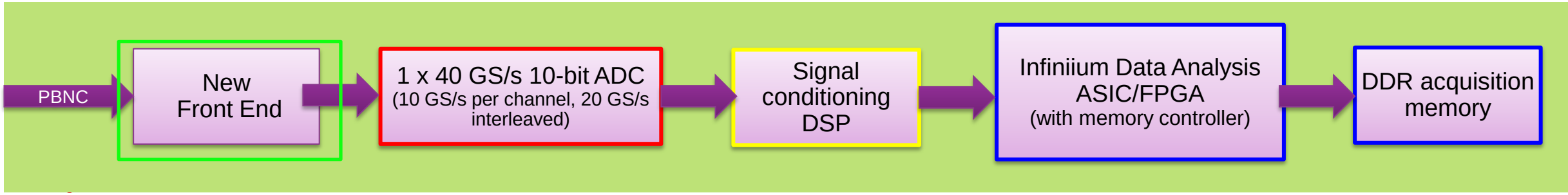


高速芯片和信号处理技术在仪表中的应用

对信号进行非线性补偿和插值拟合

Infiniium S-series





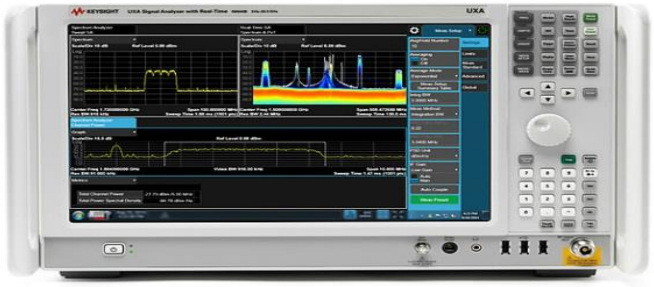
现代频谱仪里的分析软件

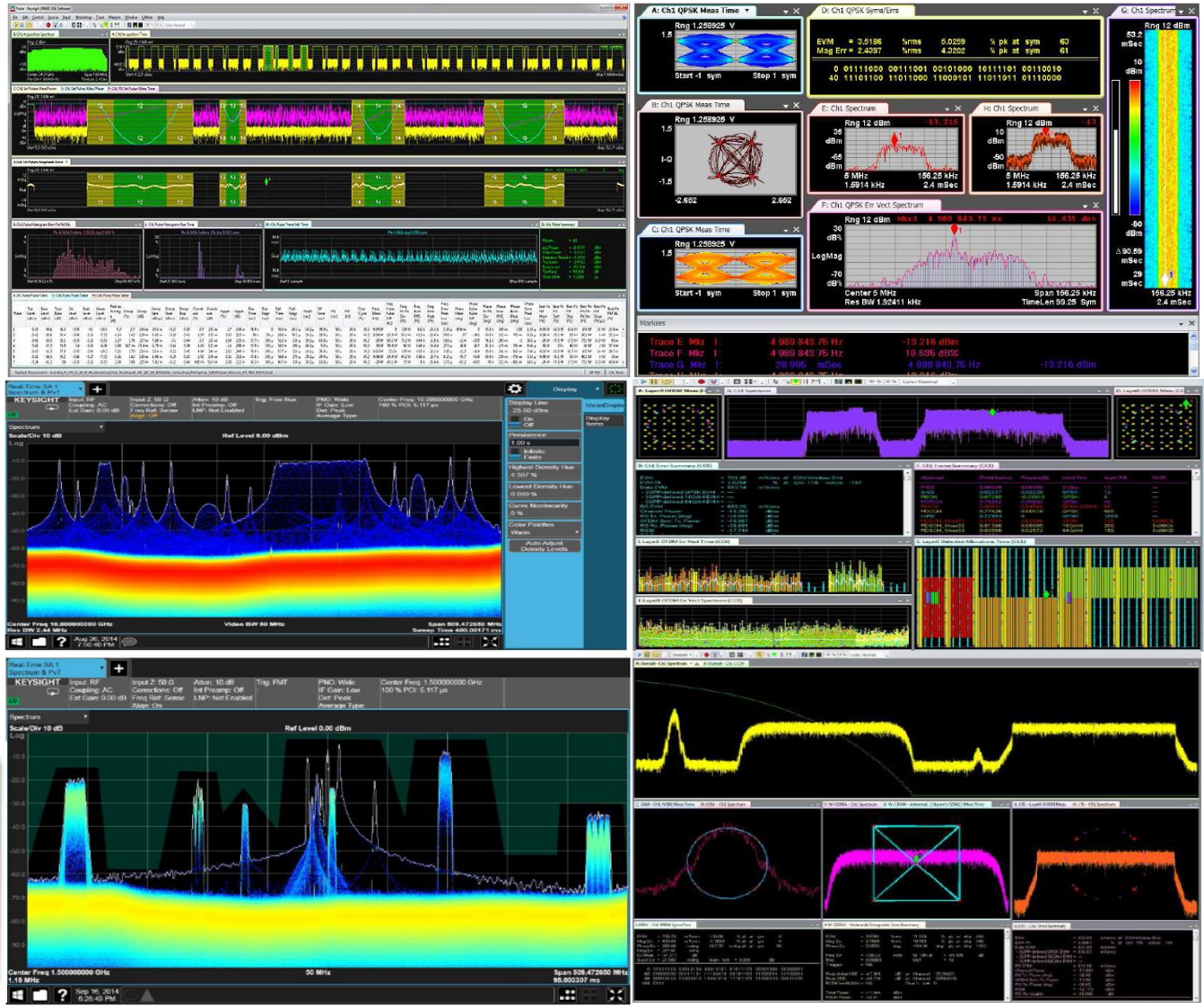
- Real-time spectrum analysis(RTSA)
- Radar pulse measurements
- LTE- Advanced, LTE, W-CDMA,HSPA+, GSM/EDGE, cdma2000®, TD-SCDMA

– 802.11ac, 802.11a/b/g/n, *Bluetooth*®, Zigbee, RFID…

– AM, FM, PM, BPSK, QPSK,QAM..

– Custom OFDM and APSK signals





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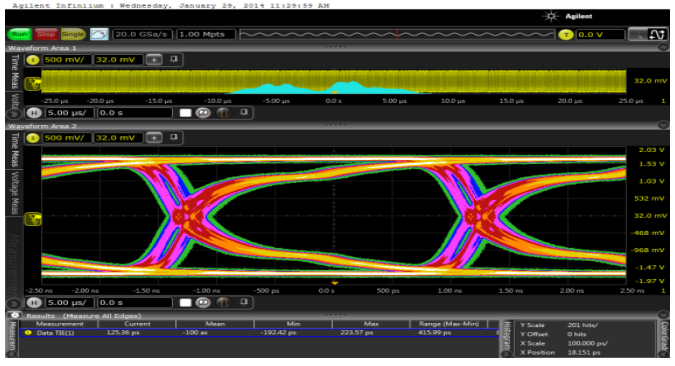
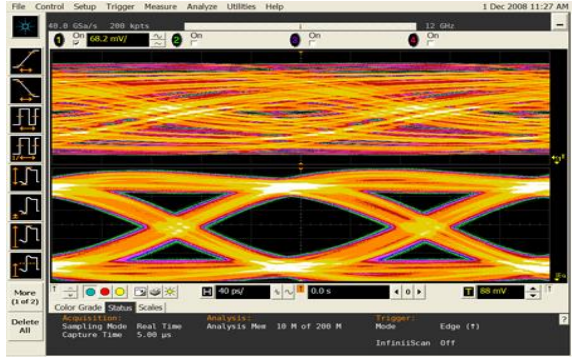
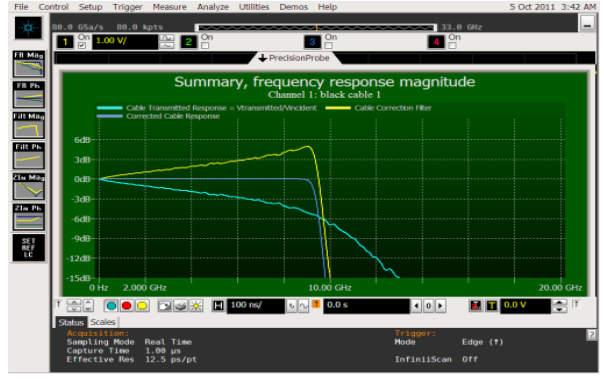
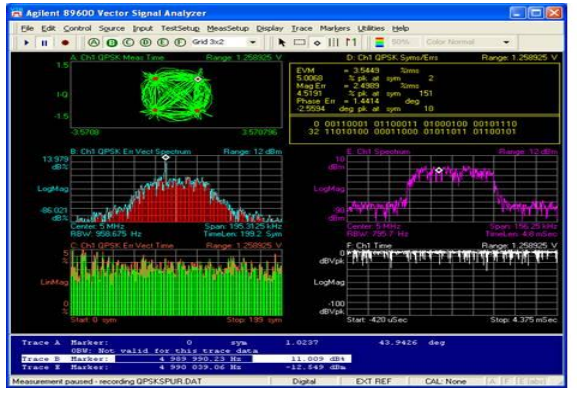
现代示波器里的分析软件

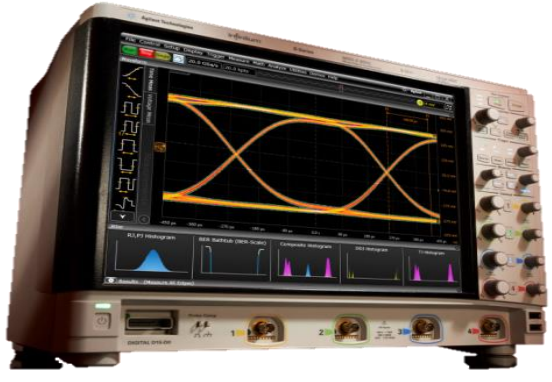
- Serial Data Analysis
- Equalization
- EZJIt/EZJIT+/EZJIT Complete
- Clock Recovery
- InfiniiScan
- Infiniisim Basic/Advanced
- Matlab integration
- Power
- Compliance test: USB,Ethernet, PCIE,SATA,DDR,MIPI,10GE…
- Protocol decode: I2C,SPI,USB, I2S,JTAG,USB,SATA,PCIE,MIPI…
- UDA (User-defined application)
- UDF (User-Defined Function)
- VSA (Vector Signal Analysis)











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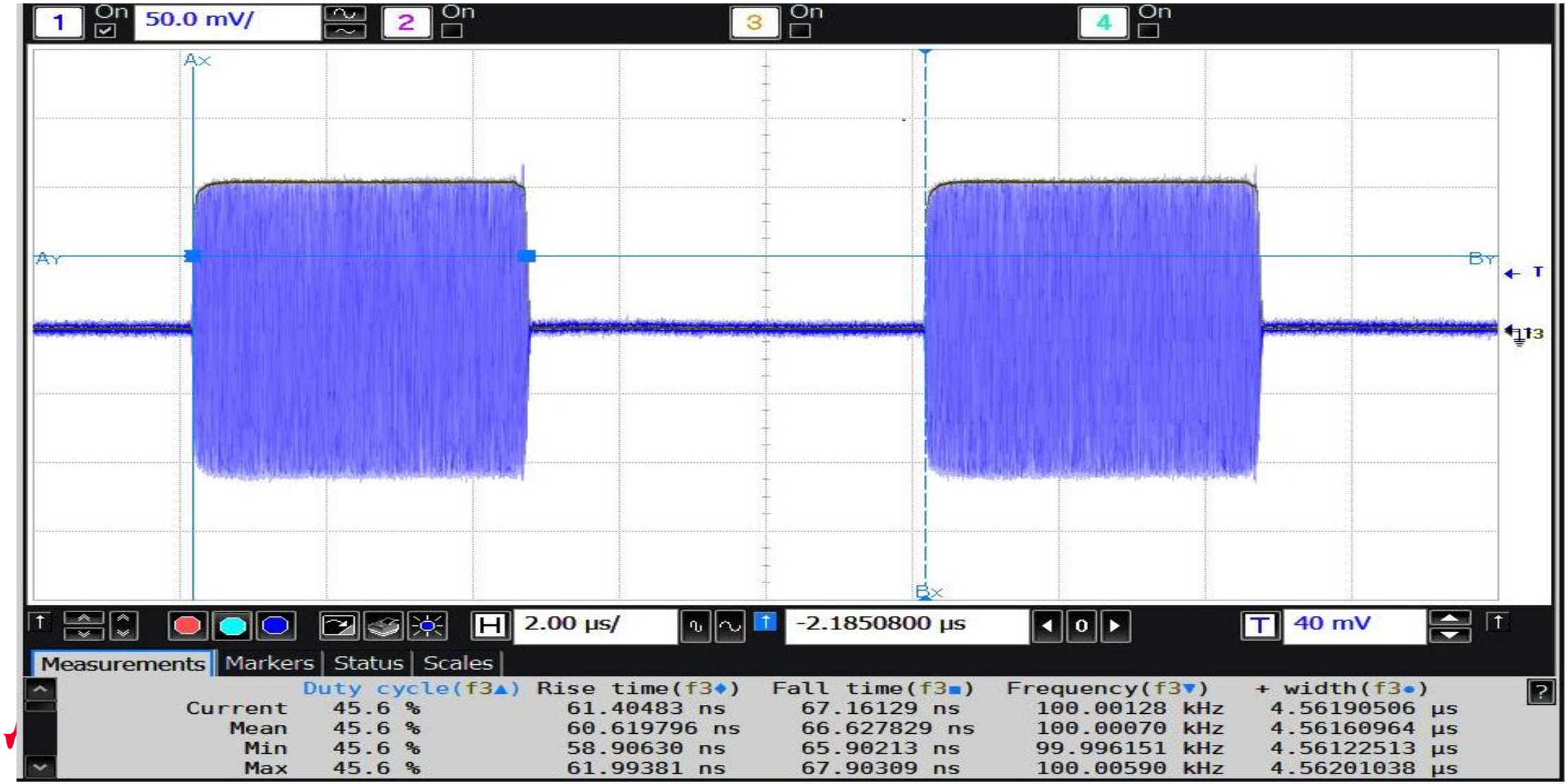
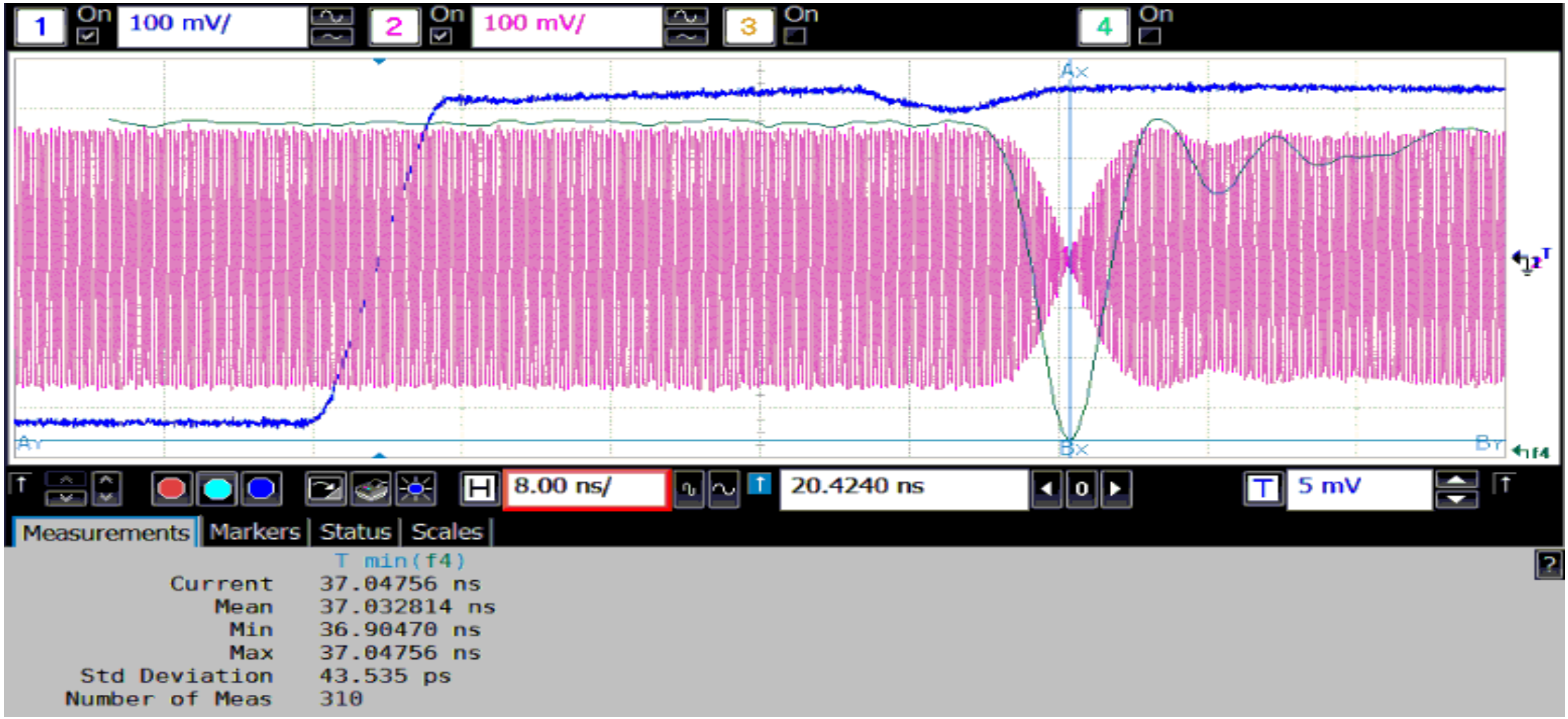
时域和频域测量中不同的术语

常用术语	时域的理解	频域的理解
Bandwidth	DC to a BW	Bandwidth around a center frequency
Wideband	1GHz or more	10MHz or more
DC	DC (like a battery)	Anything less than 9KHz
Channel	Connector on front of instrument	Communication medium
Offset	Voltage from DC	Frequency from center
50 Ohm termination	50 Ohms to ground- or (for BERTs and some probes) to a Vterm.	50 Ohms AC coupled.

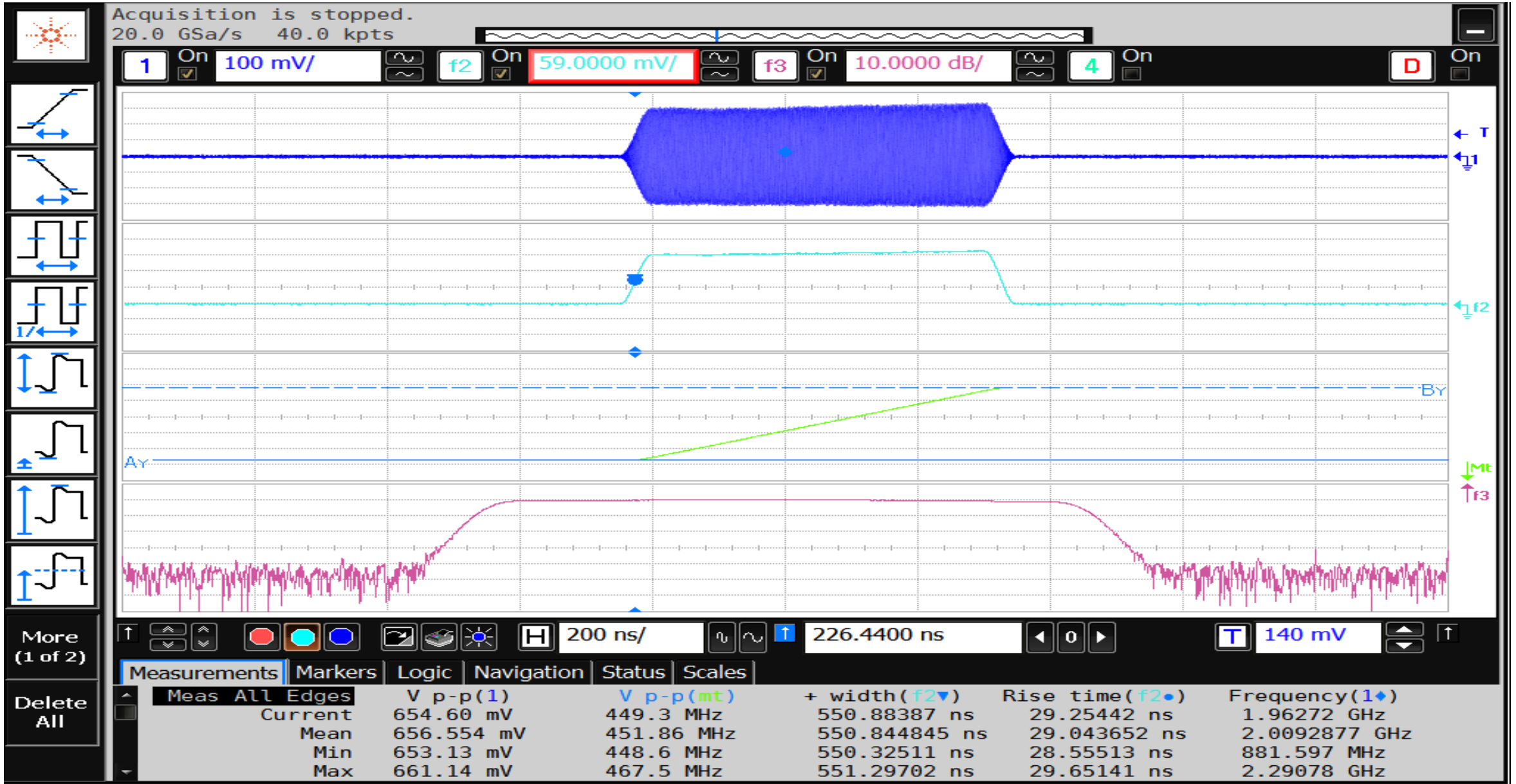
用示波器测量脉冲调制信号时域参数



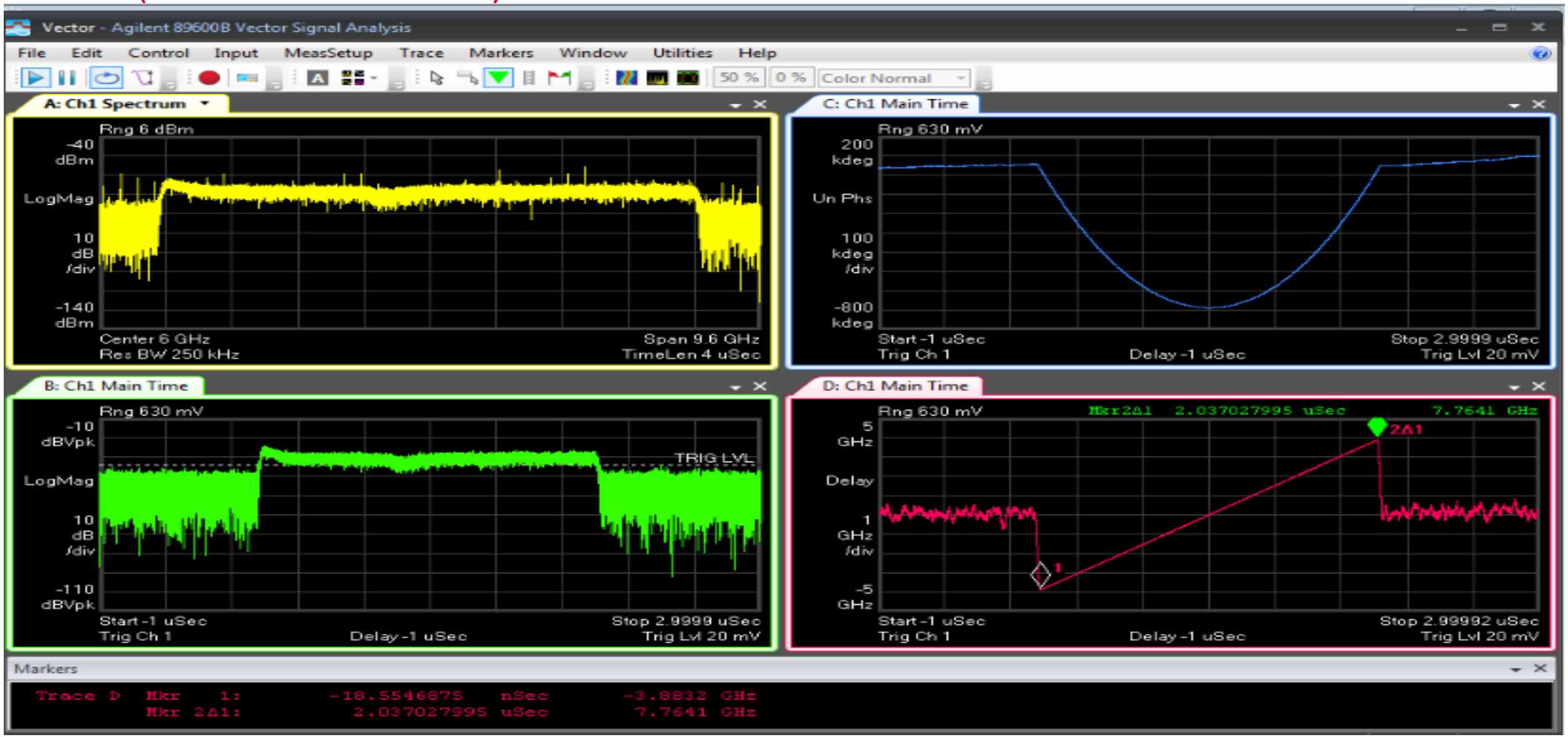
用示波器测量BPSK/QPSK调制器时延



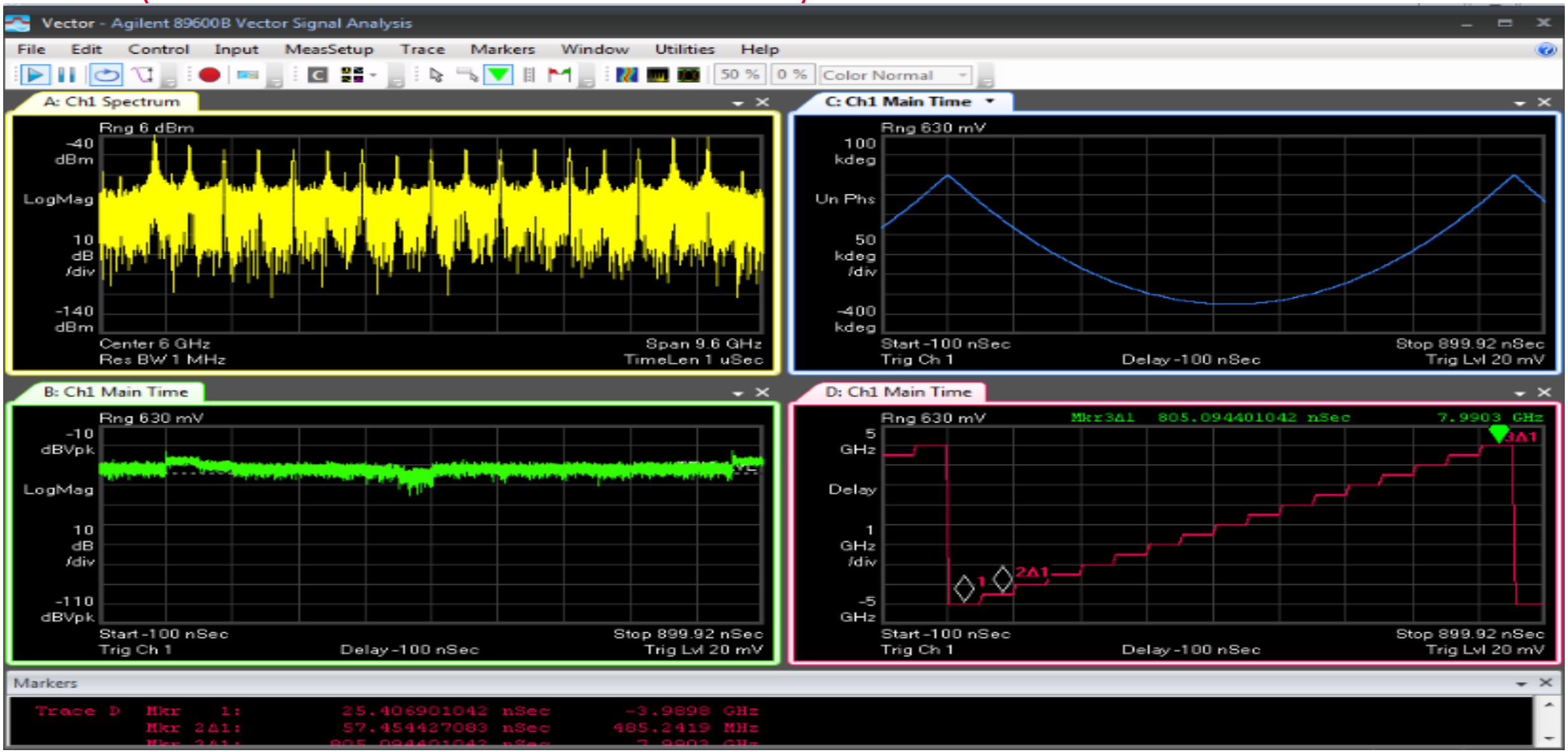
用示波器测量Chirp 雷达信号



结合矢量解调软件对超宽带Chirp信号解调分析
(举例：7GHz带宽)



结合矢量解调软件做超宽带跳频分析
(举例：7GHz带宽，500MHz步进)



结合矢量解调软件对雷达脉冲进行参数统计

Option BHP

- Automotive radar

Option BHQ:

– Pulse Analysis

– A/D radar and EW

– General purpose radar

Option BHL:

– Channel Quality Measurements

– Multi-tone group delay for satellite

Pulse	Segment	Top Level (dBm)	Base Level (dBm)	Top/Base (dB)	Droop (dB)	Overshoot (dB)	Ripple (dB)	Rise Time (sec)	Rise Edge (sec)	Fall Time (sec)	Fall Edge (sec)	Width (sec)	PRI (sec)	Duty Cycle (%)	Freq Mean (Hz)	Freq Error RMS (Hz)	Phase Mean (deg)	Phase Error RMS (deg)
1	1	655.5 m	-58.03	58.69	145 m	74.8 m	97.8 m	8.29811 n	0	7.70973 n	3.00069 µ	3.00069 µ	999.999 µ	300 m	-29.99996 M	8.92104 k	-45.399	120.9 m
2	2	-1.976	-55.95	53.98	-230 m	145 m	129 m	9.57889 n	999.999 µ	10.8264 n	1.004 m	4.0028 µ	1 m	400 m	-69.99999 M	8.32369 k	-3.2048	160.5 m
3	3	100.2 m	-58.11	58.21	-10.8 m	567 m	91.2 m	6.59519 n	2 m	5.81243 n	2.001 m	1.00022 µ	1 m	100 m	29.99946 M	7.49534 k	-62.714	142.3 m
4	4	524.6 m	-58.86	59.38	56.2 m	272 m	93.2 m	18.2773 n	3 m	18.6298 n	3.002 m	2.0012 µ	1 m	200 m	70.0005 M	8.84389 k	-57.834	118.1 m
5	5	654.8 m	-57.91	58.56	143 m	77 m	104 m	8.31015 n	4 m	7.71791 n	4.003 m	3.00067 µ	999.999 µ	300 m	-30.00013 M	7.66227 k	-56.162	122.6 m
6	6	-1.982	-56.43	54.45	-231 m	98.9 m	150 m	9.56992 n	5 m	10.7731 n	5.004 m	4.00273 µ	1 m	400 m	-69.9999 M	8.40691 k	-68.597	162.6 m
7	7	99.87 m	-58.31	58.41	-28.6 m	547 m	90.7 m	6.55577 n	6 m	5.91175 n	6.001 m	1.00019 µ	1 m	100 m	30.0005 M	10.4987 k	-73.724	165.3 m

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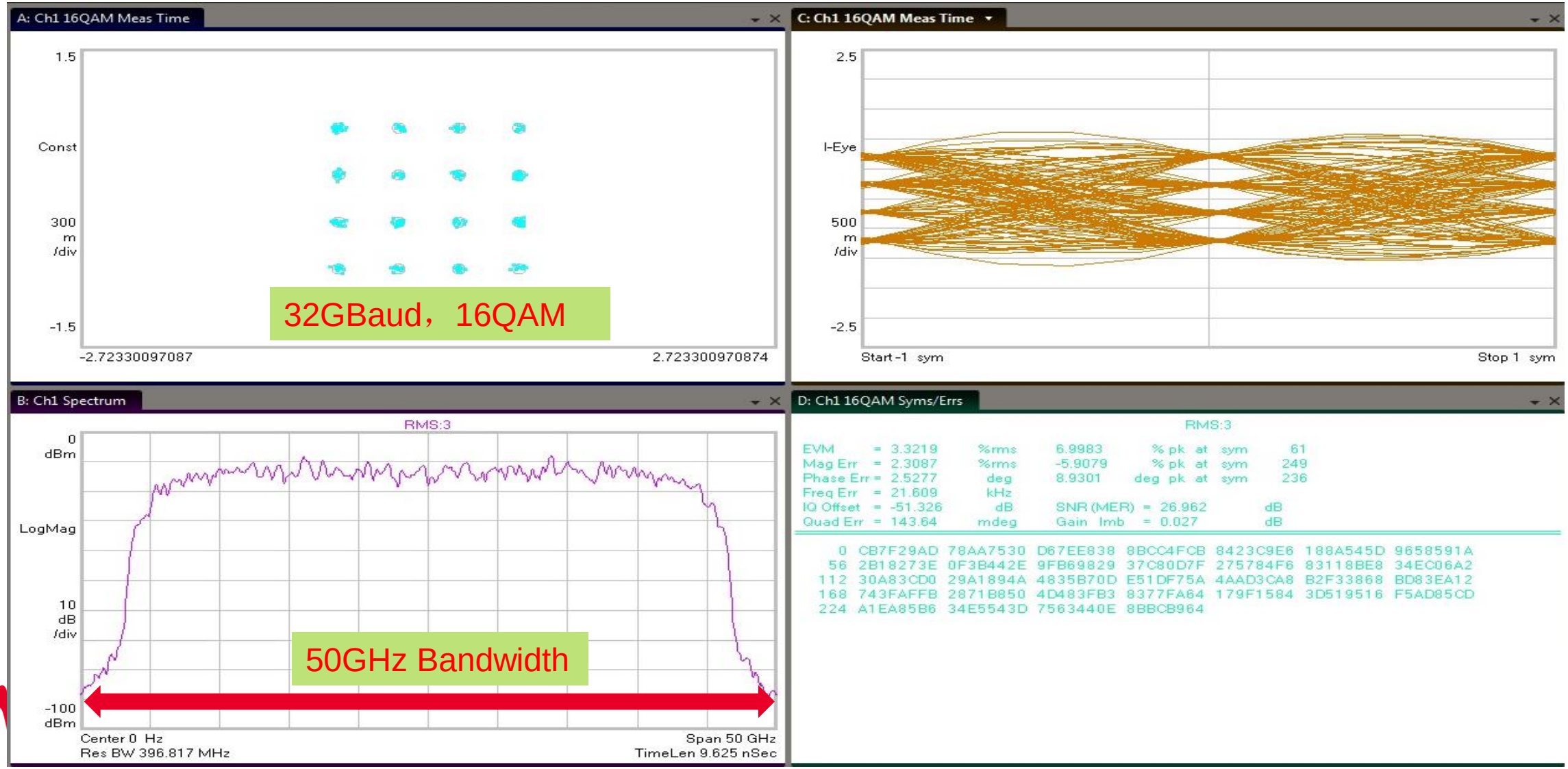
光通信和卫星通信中超宽带调制信号解调分析



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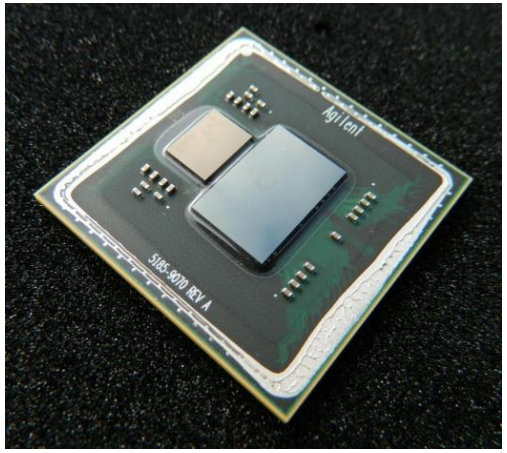
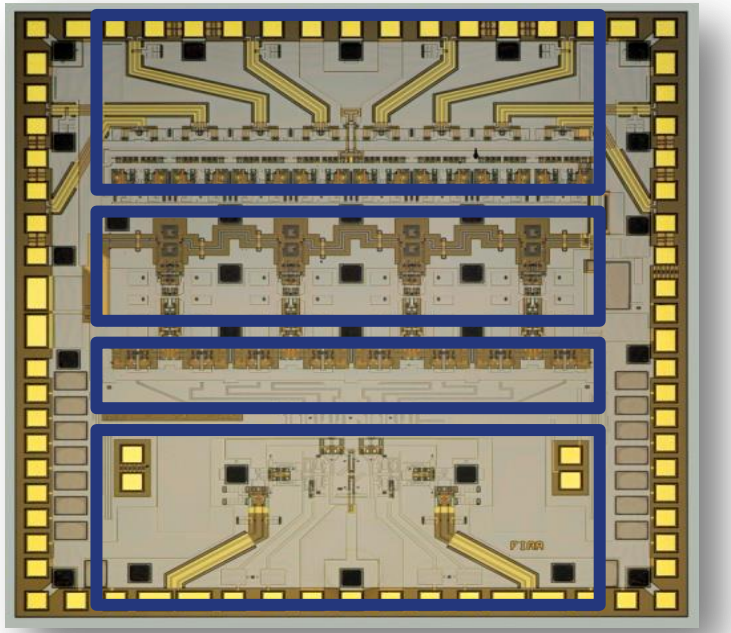
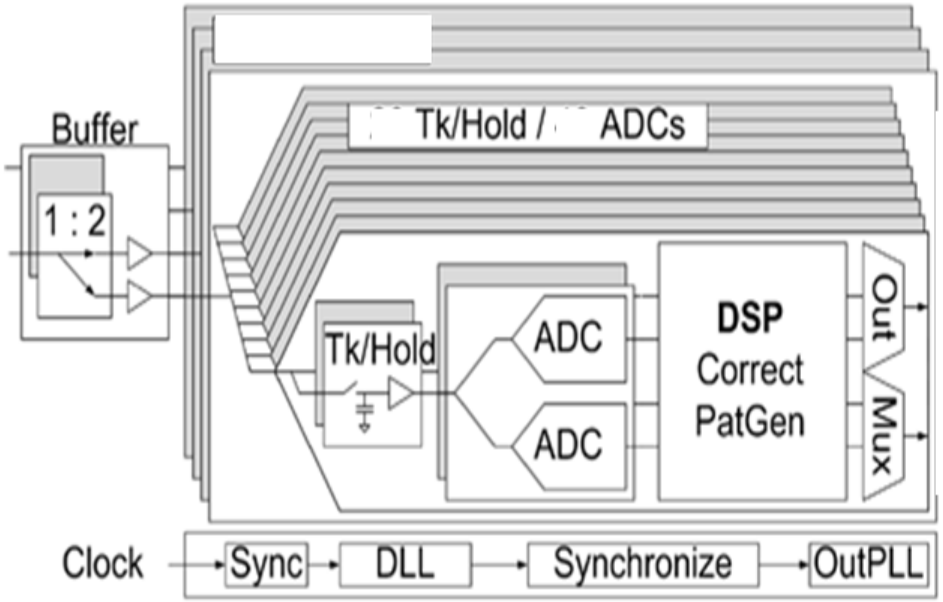
示波器ADC采样技术的革新



EvolutionWorlds fastest
10 bit ADC (40GSa/s)

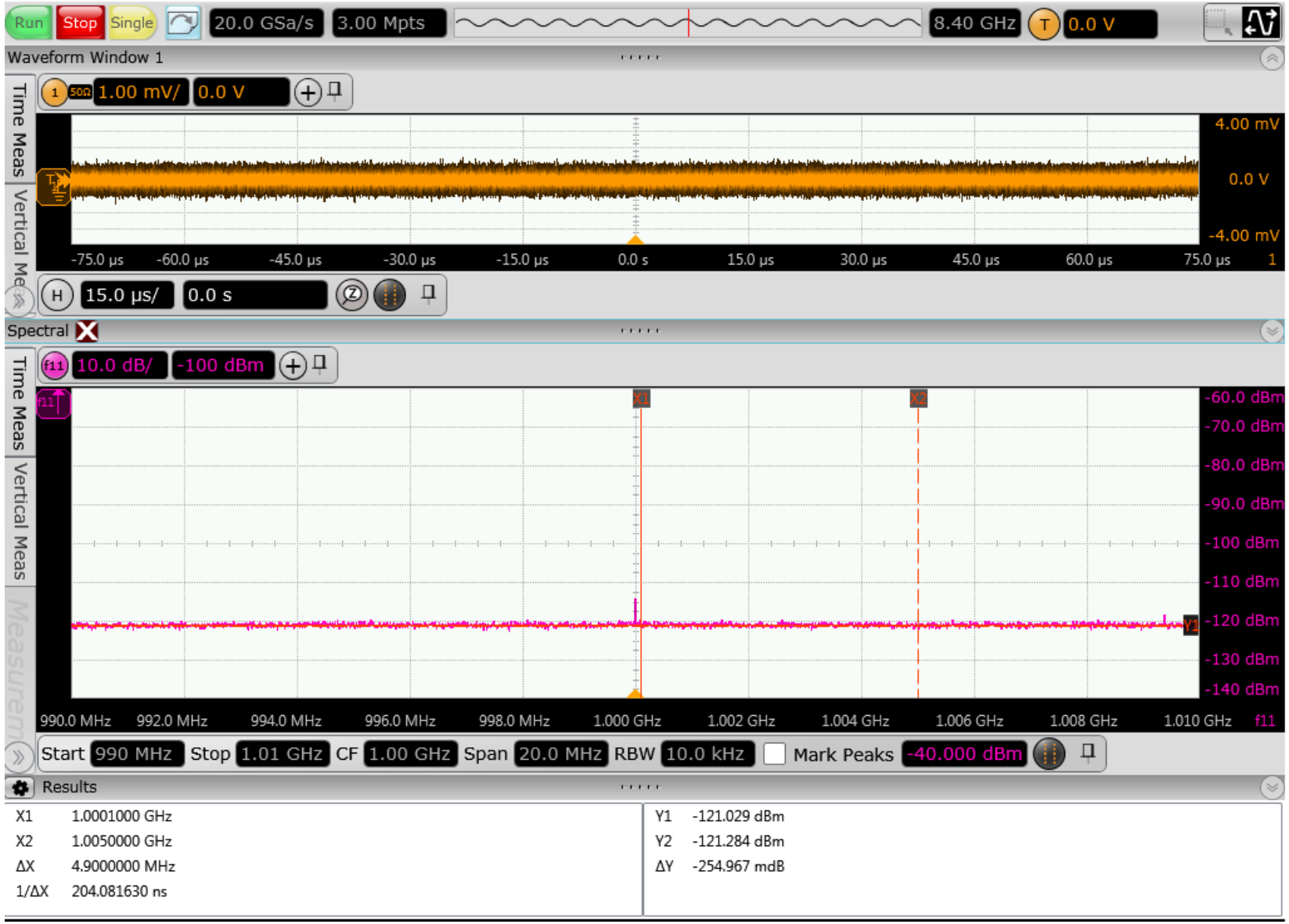




- Multiple slices
- 4x10GSa/s or 2x20GSa/s
- 10+ bit pipelined ADC
- Very low metastability

Then Hybrid Filter Bank Technology to get to **160 Gsa/sec** sampling

示波器真实的底噪声（以Keysight S系列示波器为例）



SPAN: 20MHz

RBW: 10kHz

Vertical: 1mV/div

DANL: -161dbm/Hz

Y1 -121.029 dBm

Y2 -121.284 dBm

根据示波器的Spec计算DANL

Scope design driven by time domain constraints.

From S-Series Datasheet.

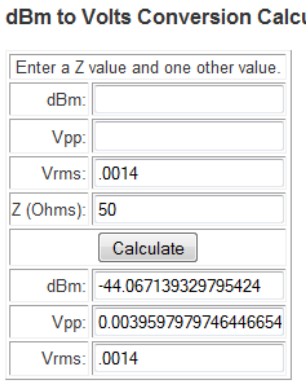
RMS noise floor (Vrms ac)

Vertical setting (Volts/div)	S-054A	S-104A	S-204A	S-254A	S-404A	S-604A	S-804A
1 mV/div	74 uV	90 uV	120 uV	130 uV	153 uV	195 uV	260 uV
2 mV/div	74 uV	90 uV	120 uV	130 uV	153 uV	195 uV	260 uV
5 mV/div	77 uV	94 uV	129 uV	135 uV	173 uV	205 uV	320 uV
10 mV/div	87 uV	110 uV	163 uV	172 uV	220 uV	256 uV	390 uV
20 mV/div	125 uV	163 uV	233 uV	254 uV	330 uV	446 uV	620 uV
50 mV/div	372 uV	456 uV	610 uV	650 uV	768 uV	1.3 mV	1.4 mV
100 mV/div	0.78 mV	0.96 mV	1.2 mV	1.3 mV	1.6 mV	2.3 mV	3.1 mV
200 mV/div	1.6 mV	2.0 mV	2.6 mV	2.8 mV	3.4 mV	4.9 mV	6.4 mV
500 mV/div	3.5 mV	4.2 mV	5.5 mV	6 mV	7.3 mV	10.0 mV	13.3 mV
1 V/div	5.1 mV	6.8 mV	9.2 mV	10.1 mV	12.5 mV	17.6 mV	24.1 mV

Translated (calculated) to RF-Speak!
(8GHz Model Only)

V/div	dBm Ref Level	dBm/Hz Noise
1mV/div	-28 dBm	-158 dBm/Hz **
2mV/div	-28 dBm	-158 dBm/Hz
5mV/div	-24 dBm	-156 dBm/Hz
10mV/div	-18 dBm	-154 dBm/Hz
20mV/div	-12 dBm	-150 dBm/Hz
50mV/div	-4 dBm	-143 dBm/Hz
100mV/div	+2 dBm	-136 dBm/Hz
200mV/div	+6 dBm	-130 dBm/Hz
500mV/div	+16 dBm	-124 dBm/Hz
1V/div	+22 dBm	-118 dBm/Hz

http://www.coretechgroup.com/dBm_Calculator.php



- 50mV/div = 400mV full scale (Vpp) = -4dBm range.
- 4mV rms noise = -44dBm @ 8GHz = -143dBm/Hz

** Does not exactly match measured, assumed no noise in 8-10GHz.

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数字处理技术对于示波器信噪比的提升

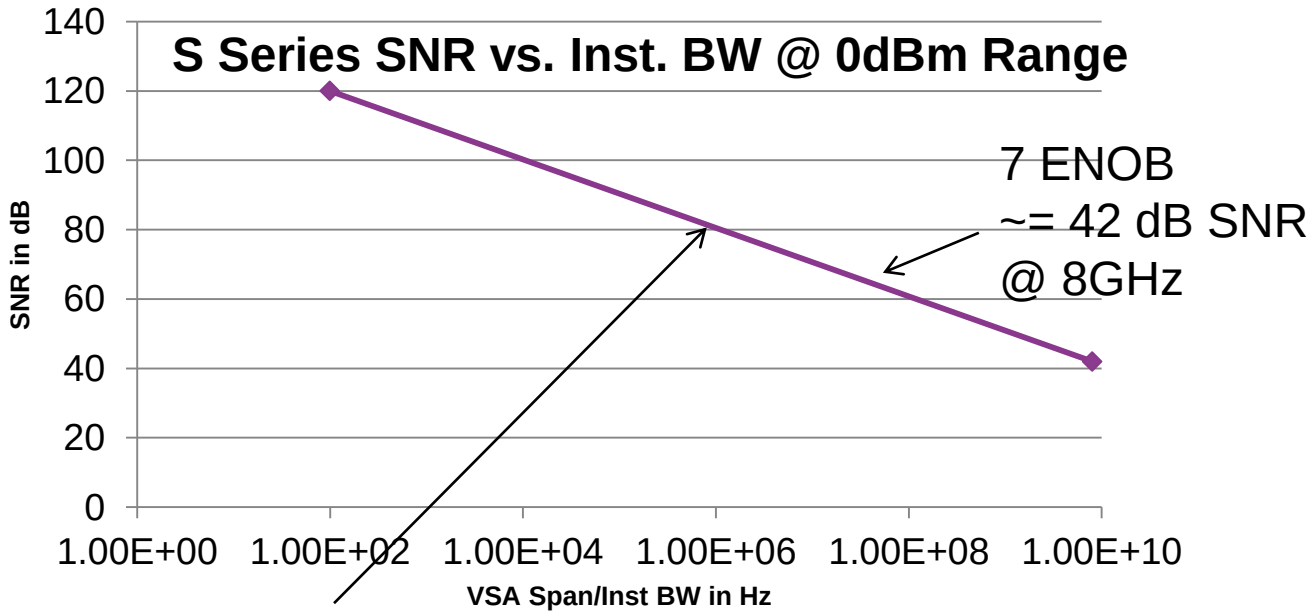
降低带宽→降低噪声→提高SNR →提高ENOB

- Quantization Error is best modeled as NOISE.
- All real ADCs have more noise than that
- SNR is improved by 10log*(ScopeBW/Span). (Wideband Signals)
- DR is improved by 10log*(ScopeBW/RBW) . (Narrowband Signals)
- ~1 bit ENOB per 4x BW reduction

$$\mathrm{SQNR} = 20\log_{10}(2^Q) \approx 6.02 \cdot Q \ \mathrm{dB}$$

$$\mathrm{ENOB} = \frac{\mathrm{SINAD} - 1.76}{6.02}$$

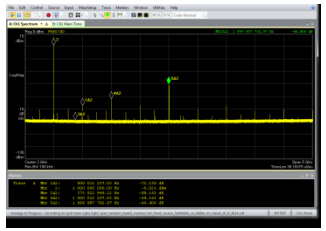
1.76 due to using sine wave for ENOB measurement.
Not uniformly distributed.



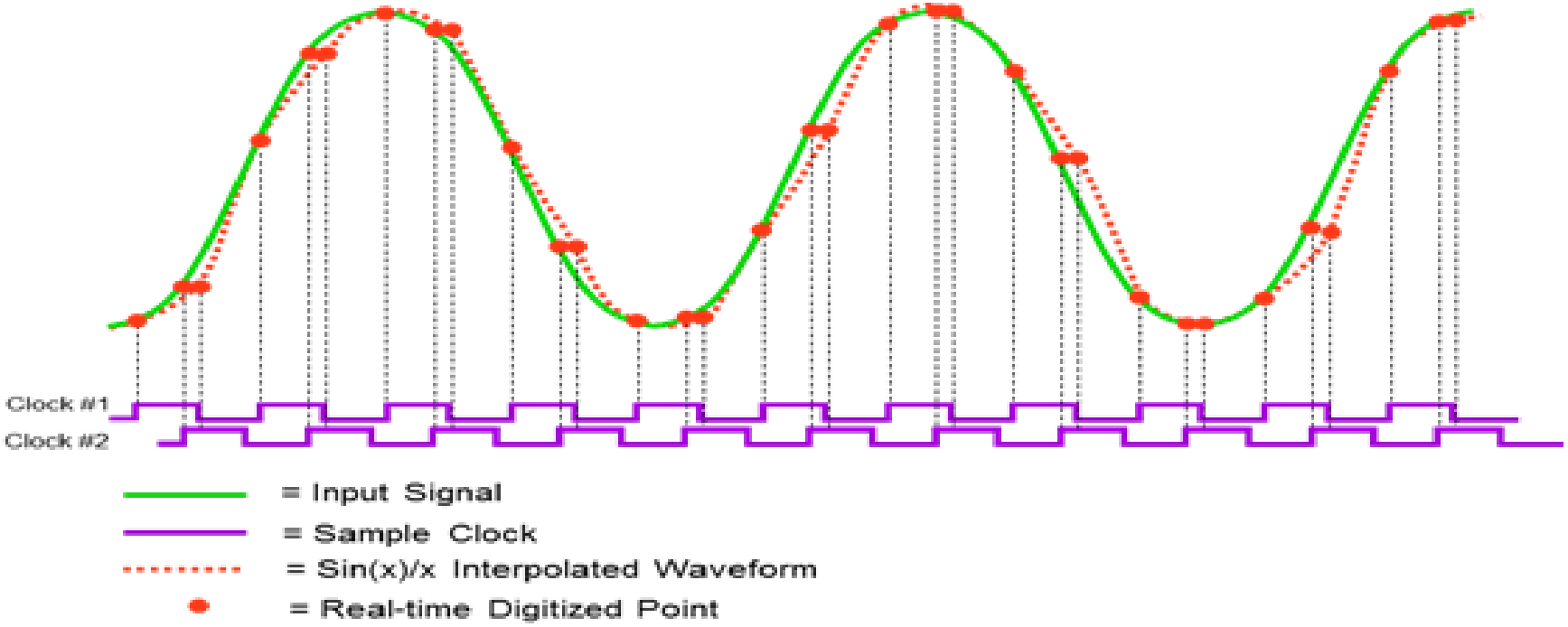
KEYSIGHT TECHNOLOGIES

示波器杂散的来源

ADC交织不理想造成的失真



- ADC Interleave leads to evenly spaces residual spurs do to gain and offset DC mismatch.
- ADC Interleave also leads to other spurs as frequencies beat/mix with inputs.
- At high gain (sensitivity), other fixed spurs appear that approach Interleave residuals in magnitude.



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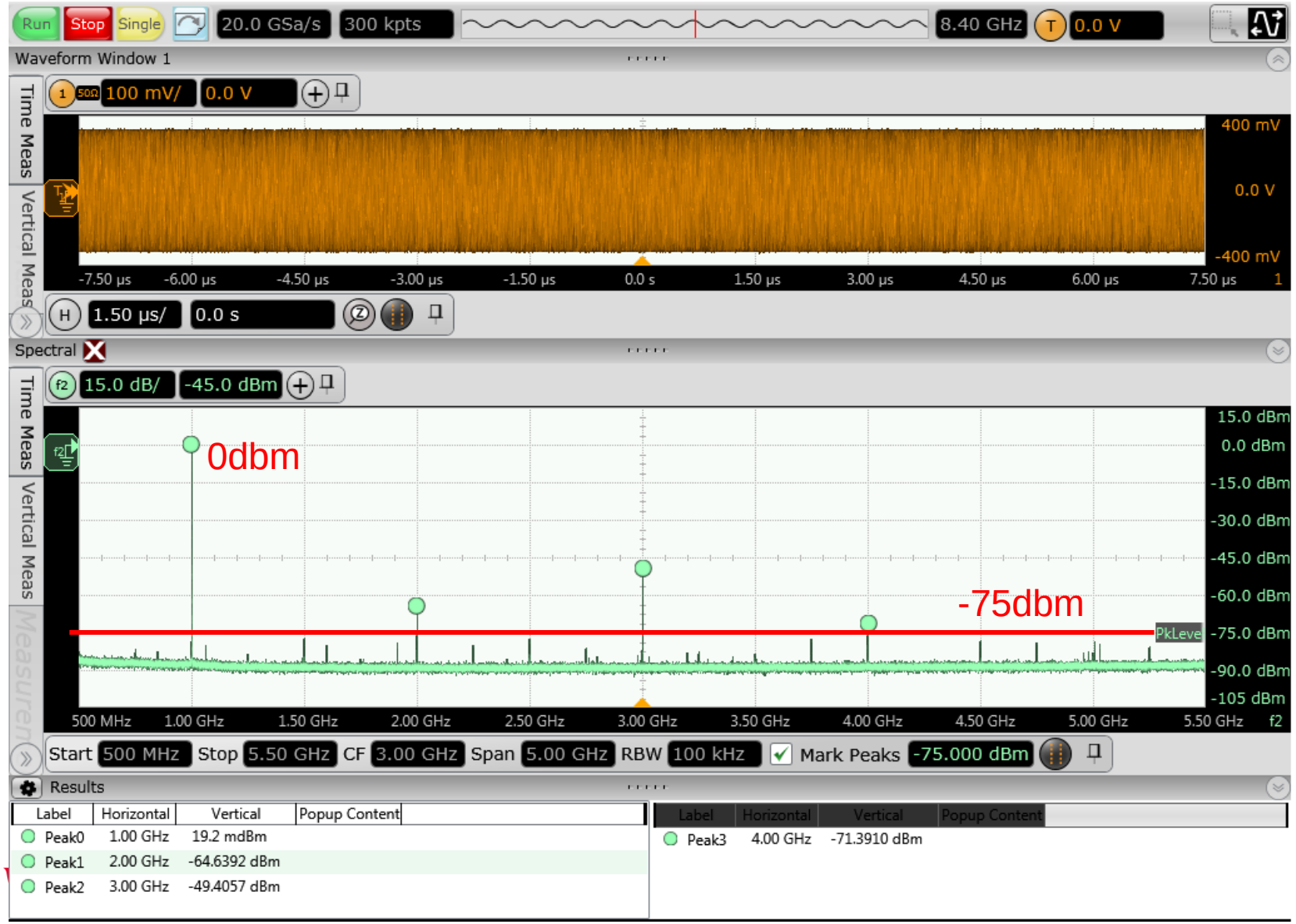
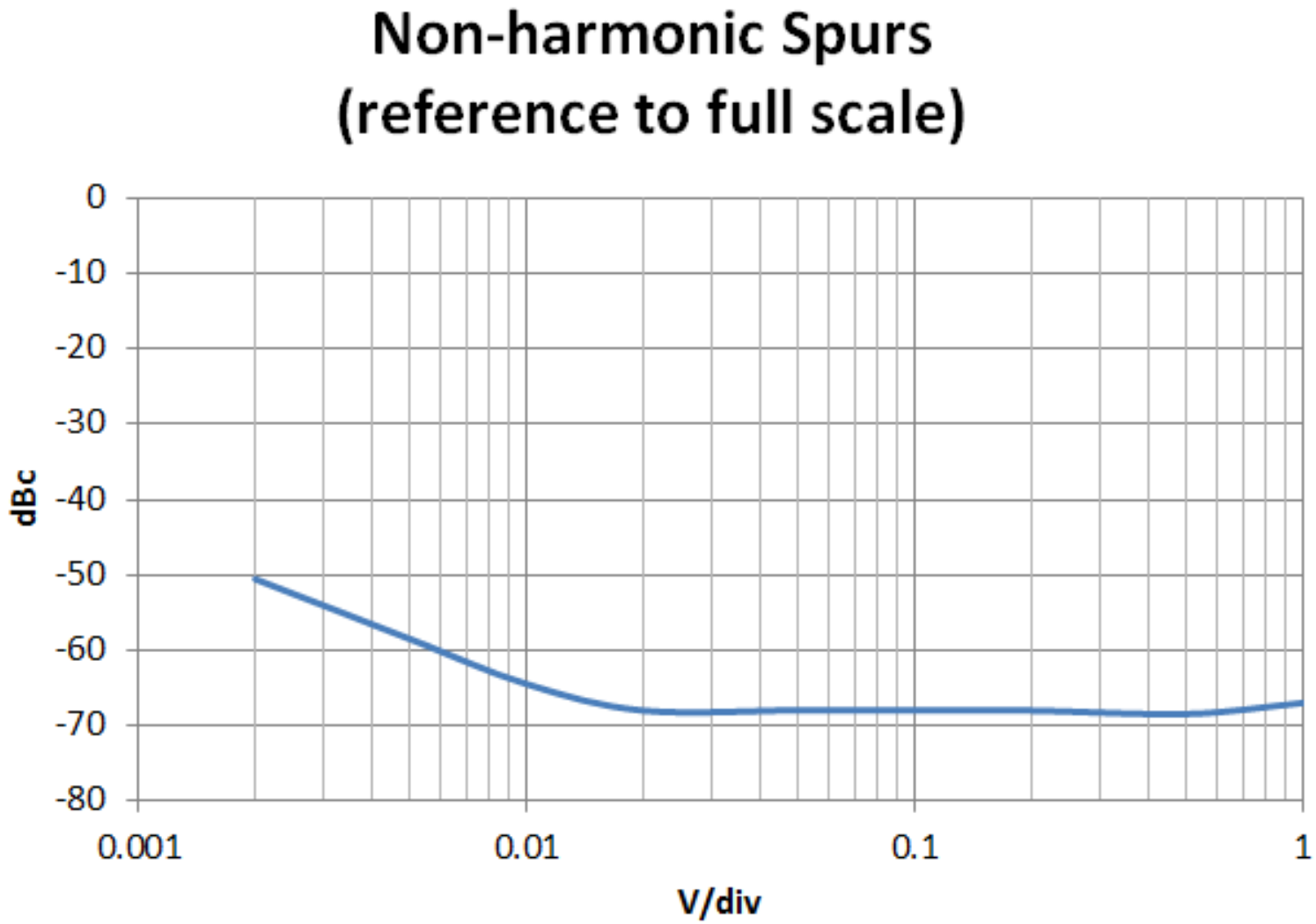
Keysight S系列示波器的杂散和谐波失真



Center：3GHz
Span：5GHz
RBW: 100KHz
Vertical：15db/div
CW Freq：1GHz
CW Amp：0dbm

Peak0	1.00 GHz	19.2 mdBm
Peak1	2.00 GHz	-64.6392 dBm
Peak2	3.00 GHz	-49.4057 dBm

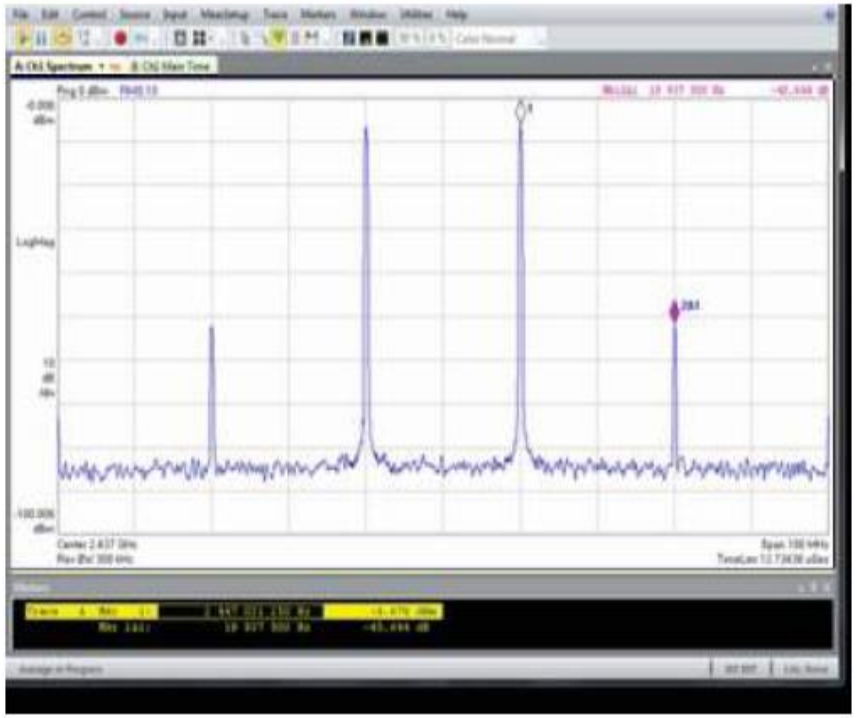
Keysight S系列示波器在不同量程下的杂散指标



KEYS TECHNO

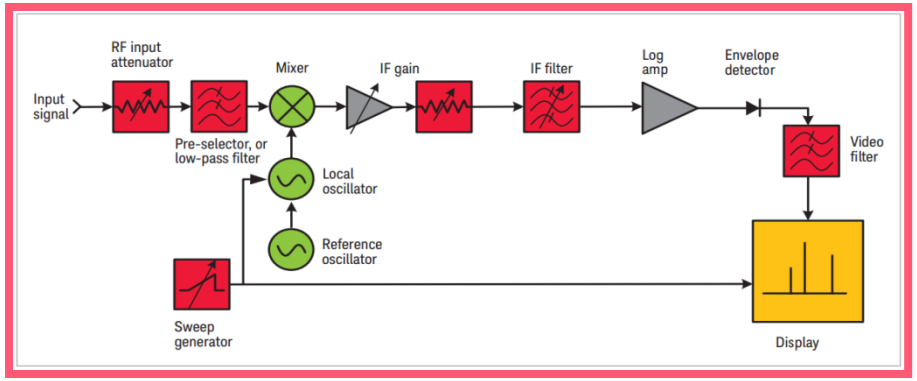
现代示波器里的频域指标

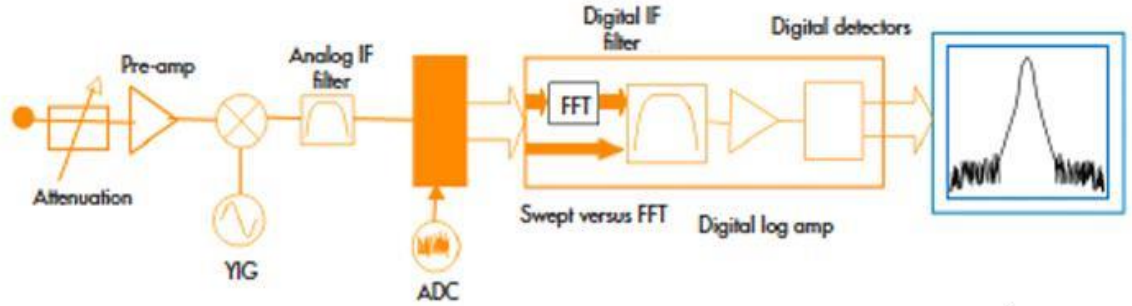
Typical RF characteristic values from measured results on an 8-GHz S-Series oscilloscope	
Sensitivity / noise density (1 mV/div; -38 dBm range) Power spectral density measurement at 1.0001 GHz, 1.0001 GHz center frequency, 500 kHz span, and 3 kHz RBW	-160 dBm/Hz
Noise figure (derived from measurement above)	14 dB
Signal-to-noise ratio / dynamic range (0 dBm 1 GHz input carrier, 0 dBm scope input range) 1 GHz center frequency, 100 MHz span, 1 kHz RBW, measurement at +20 MHz from center	108 dB
Absolute amplitude accuracy (0 to 7.5 GHz)	± 1 dB
Deviation from linear phase (0 to 7.5 GHz)	± 7 deg
Phase noise (at 1 GHz)	
10 KHz offset	-121 dBc/Hz
100 KHz offset	-122 dBc/Hz
EVM (802.121 2.4 GHz carrier, 20 MHz wide, 64 QAM)	-47 dB (0.47%)
Spurious responses (0 dBm signal, 0 dBm input range) **Spur Free Dynamic Range (SFDR)** 1 GHz, 0 dBm signal present at input, FFT =5 GHz span, 3 GHz center, 100 kHz RBW	72 dB
2nd harmonic distortion 1 GHz input, 0 dBm, 5 GHz span, 3 GHz center, 100 KHz RBW	-64 dBc
3rd harmonic distortion 1 GHz input, 0 dBm, 5 GHz span, 3 GHz center, 100 KHz RBW	-46 dBc
Two-tone Third-Order Intermodulation (TOI) distortion 0 dBm input tones, 2.435 GHz and 2.439 GHz, 2 MHz separation, 2.437 GHz center frequency, 10 MHz span, 100 kHz RBW, 6 dBm input range	+21.5 dB

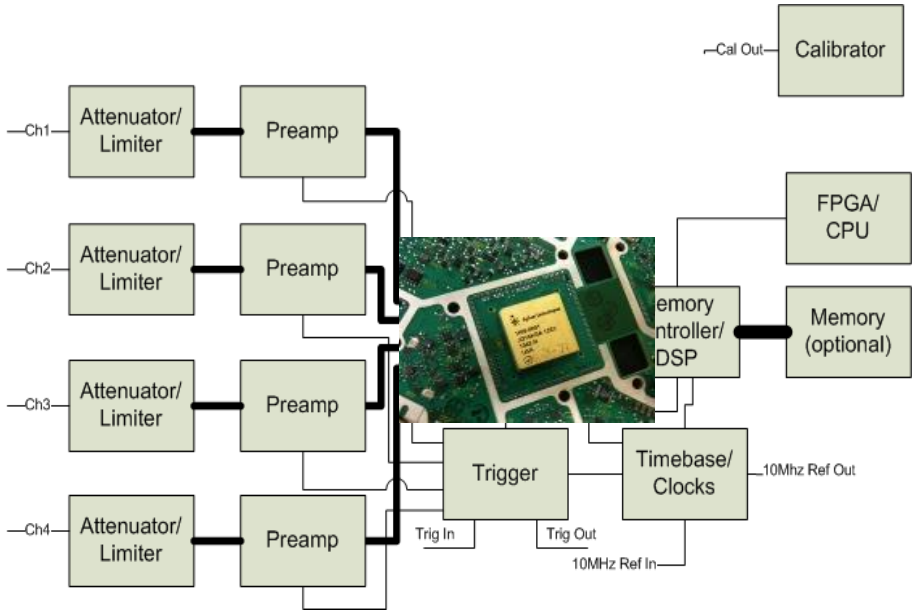


Using data acquired from S-Series, VSA shows an excellent TOI value of 21.5 dB.

示波器的未来发展趋势


RF input attenuator
Mixer
IF gain
IF filter
Log amp
Envelope detector
Input signal
Pre-selector, or low-pass filter
Local oscillator
Reference oscillator
Video filter
Sweep generator
Display


Digital IF filter
Digital detectors
Pre-amp
Analog IF filter
FFT
Attenuation
YIG
ADC
Swept versus FFT
Digital log amp


Cal Out
Calibrator
Ch1
Attenuator/ Limiter
Preamp
Ch2
Attenuator/ Limiter
Preamp
Ch3
Attenuator/ Limiter
Preamp
Ch4
Attenuator/ Limiter
Preamp
FPGA/ CPU
emory ntroller/ DSP
Memory (optional)
Trigger
Timebase/ Clocks
10Mhz Ref Out
Trig In
Trig Out
10MHz Ref In

谢谢！

Keysight频谱仪家族

Performance

Price

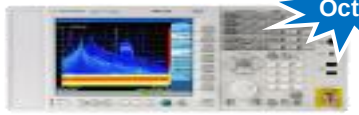
UXA

See the Real Performance

3 Hz to 26.5 GHz, **510 MHz BW**

Available with RTSA

Oct 09



PXA

Drive your Evolution

3 Hz to 50 GHz, **160 MHz BW**

Available with RTSA

Sep 06

MXA

Accelerate in Wireless

10 Hz to 26.5 GHz, **160 MHz BW**

Available with RTSA

Sep 07

EXA

Balance the Challenges

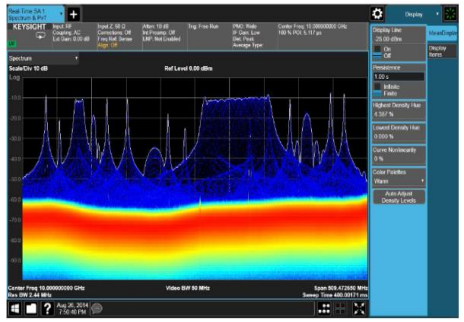
10 Hz to 44 GHz, **40 MHz BW**

Oct 09

CXA

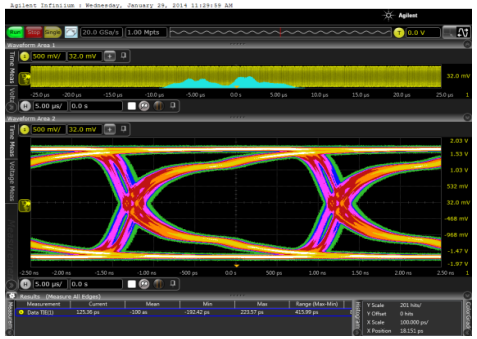
Master the Essentials

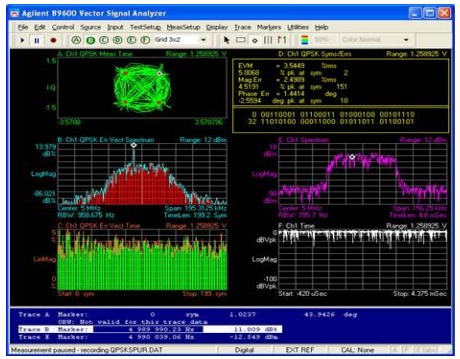
9 kHz to 26.5 GHz, **25 MHz BW**



KEYSIGHT TECHNOLOGIES

Keysight示波器家族





Infiniium

- 500 MHz to 63 GHz
- Deep memory
- Win7 OS

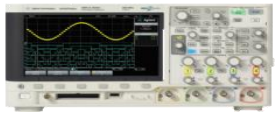
InfiniiVision

- 70 MHz to 6 GHz
- Optimized for visualization
- Embedded OS

U1600 Series

U2700 Series

1000 Series



2000 X-Series

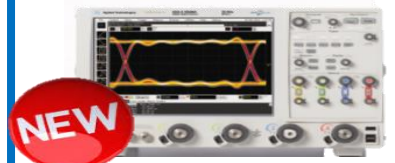
3000 X-Series

4000 X-Series

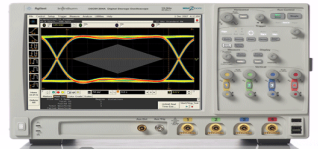
6000 X-Series

DCA-X Sampling

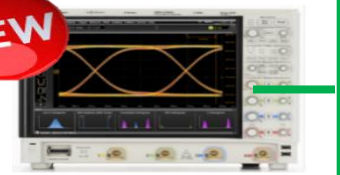
Z-Series



V-Series



90000A Series



S-Series

9000A-Series

KEYSIGHT TECHNOLOGIES