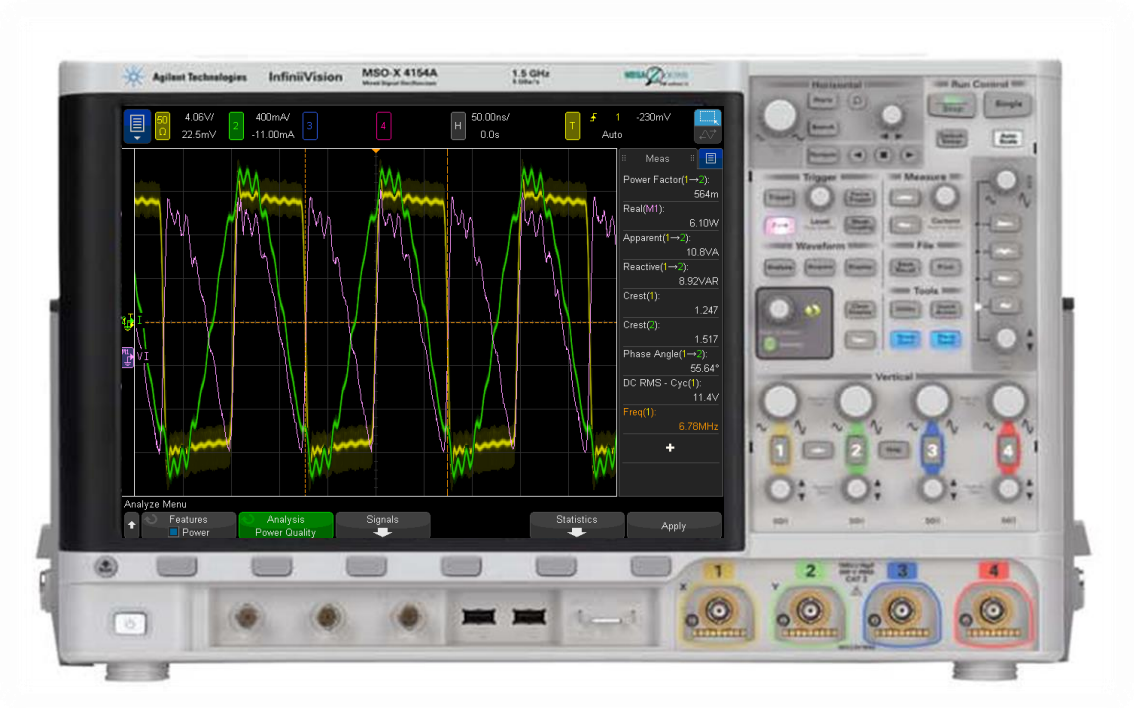
# A4WP Magnetic Resonance Wireless Charging  Measurements using an Oscilloscope

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Alliance for Wireless Power

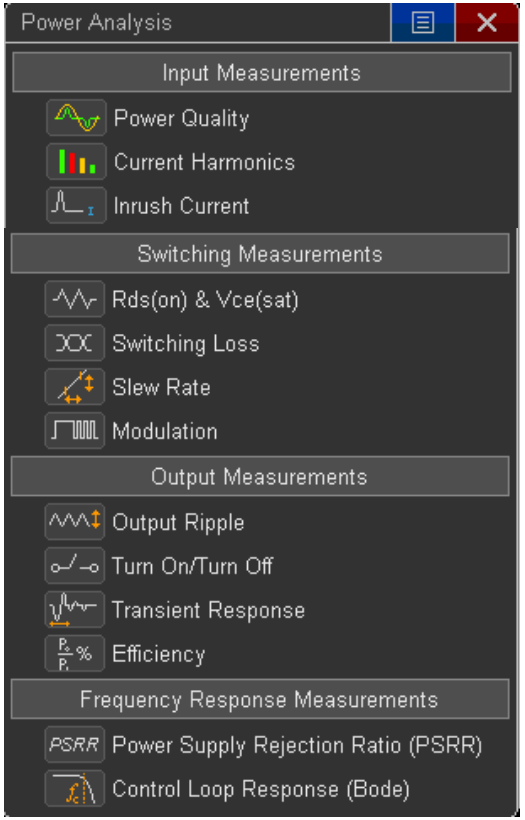
# Wireless Charger Testing Total Solution

| Keysight Offering | Recommended Models | Qty | RAT Ref. | Remark | |
|---|---|---|---|---|---|
| VNA | ● VNA Selection: | | | | |
| VNA For Compliance? | Low-power | High-power | | | |
| Yes | ● E5072A/(245 or 285)/006 or<br>● E5071C/240 (require manually calculation) or<br>● Equivalent E5061B/3L5/005/006 or E5063A/205/006 | E5072A/(245 or 285)/006 | | | |
| No | ● E5072A/(245 or 285)/006 or<br>● E5061B/3L5/005/006 (LCR/VNA in one) or<br>● E5063A/205/006 (Economic) or<br>● E5071C/240 (require manually calculation) or<br>● E5080A/245 (require manually calculation)<br>If need accurate Z measurement or high Q (>100): We can further sell either E4990A/010 (or 020 to also cover NFC @13.56MHz) or 16047E fixture to use with E5061B For high-volume test, we can add 42941-60002 SMA probe head to raise the throughput | | 1 | 4.1.2<br>4.6.2 | ● RAT Compliance: E5072A, E5071C (equivalent E5061B/E5063A)<br>● Opt.006 support: E5072A, E5061B, E5063A<br>● Require manually calculation: E5071C, E5080A |
| Attenuator | 2x 8493A Coaxial Fixed Attenuator (to protect the VNA inputs from excessive input power) (Optional) | 2 | 4.6.2 | | |
| Cal Kit | 1x Ecal 85093C (stated in 4.1.2) or cheaper mechanical cal kit 85033E (stated in 4.6.2) | 1 | 4.1.2<br>4.6.2 | | |
| Cables | ● 2x 11500F or Z5623A-K20 (RG316 Cables without Chokes, Maximum length: 3 meters、SMA(m)<br>● 7x 11500F or Z5623A-K20 (RG36 SMA Coax Cable, slim and flexible cable should be used to wind cable around choke 5 times) | 2<br>7 | 4.1.2<br>4.6.2 | Totally 9 SMA(m) cables | |
| Adaptors | 2x 1250-1744, N (m) to SMA (f) adapters | 2 | 4.1.2 | | |
| Torque Wrench | 1x 8710-1761, SMA torque wrench | 1 | 4.1.2 | | |
| Function Gen | 1x 33510B (dual channel) Function Generator | 1 | 4.3.2 | | |
| Digital Multimeter | 1x U1270 Series Handheld DMM (Recommend U1273A OLED, or U1273AX, U1272A) | 1 | 4.3.2<br>4.6.2 | | |
| Oscilloscopes | 1x DSOX3014T (at least 100 MHz bandwidth and 2 Giga Samples/Second resolution) for all current measurement<br>Recommended: If also need RCE measurement, then D(M)SOX4024A or above is required) | 1 | 4.3.2<br>4.6.2 | 4.3.2 need better scope, can upselling D(M)SOX4024A or D(M)SOS054A for efficiency test and good PI performance and it's better than Tek's MSO4014B and TCP0030 probe | |
| AC Current Probe | 2x N2893A 100MHz/15A AC/DC Current Probe (rated at least 5 Amps RMS at 6.78 MHz, bandwidth 50 MHz or more) | 2 | 4.6.2 | May need accessories using with different scopes | |
| HV Diff Probe | 2x HV Diff Probe - N2790A, 100 MHz, 50:1/500:1, ±1,400V, HV Diff Probe | 2 | 4.6.2 | | |
| De-skew Fixture | 1x U1880A Power measurement de-skew fixture for voltage and current probes<br>(or cheaper custom-made de-skew fixture that consists of just one 10-Ω resistor and a BNC-to-grabber adapter) | 1 | 4.6.2 | | |

# Objectives of Today's Presentation



Learn how to use an oscilloscope's advanced triggering, waveform math functions, and parametric measurements to fully characterize resonator current, beacon timing, power, and efficiency in magnetic resonance (A4WP) wireless charging systems.

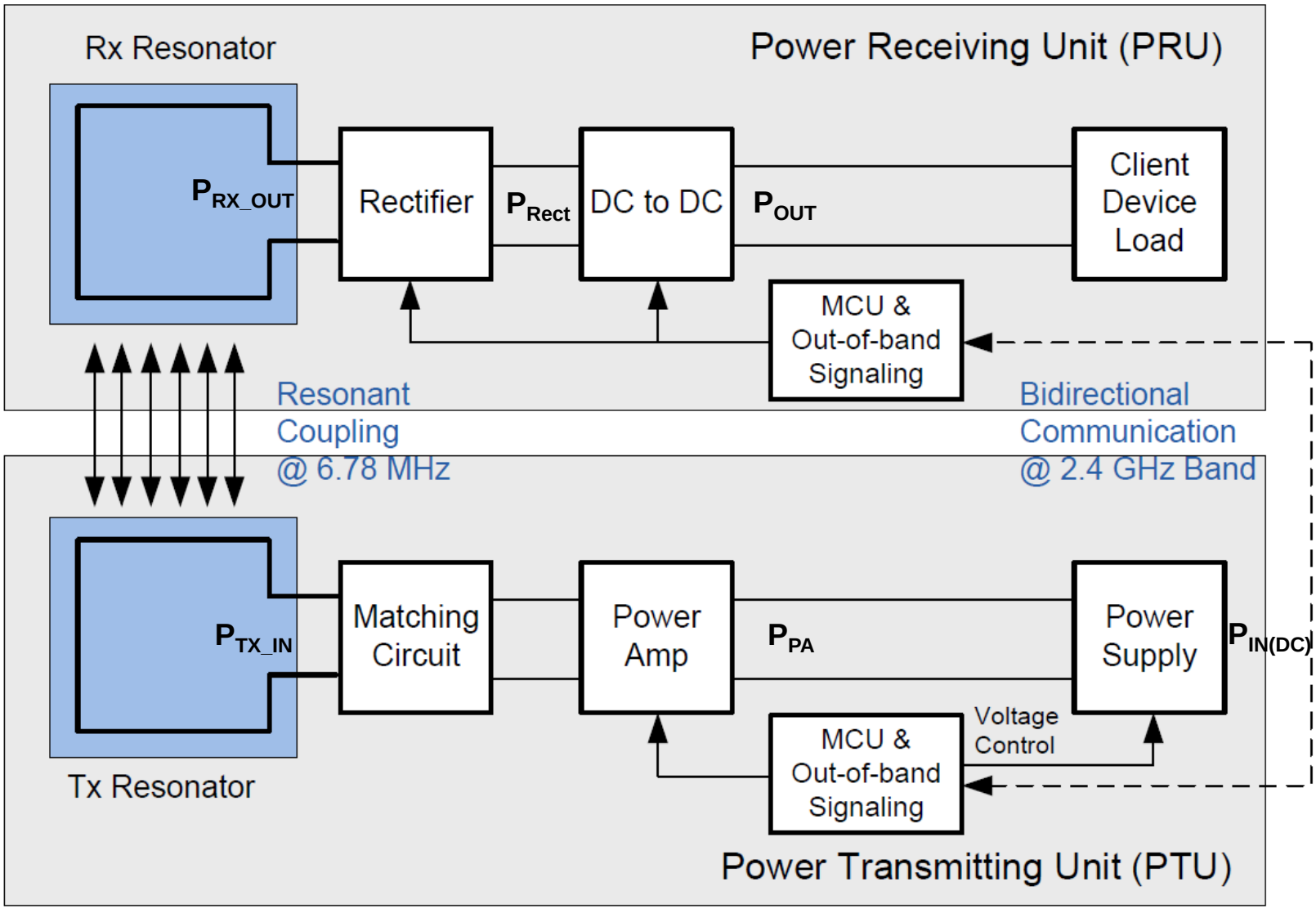


# Agenda



- Magnetic Resonant System Overview
- Required Scope Measurements & Specifications
- Triggering on Beacons
- Measurement Technique Overview
- Probe Deskew
- Demonstration
- Wrap-up

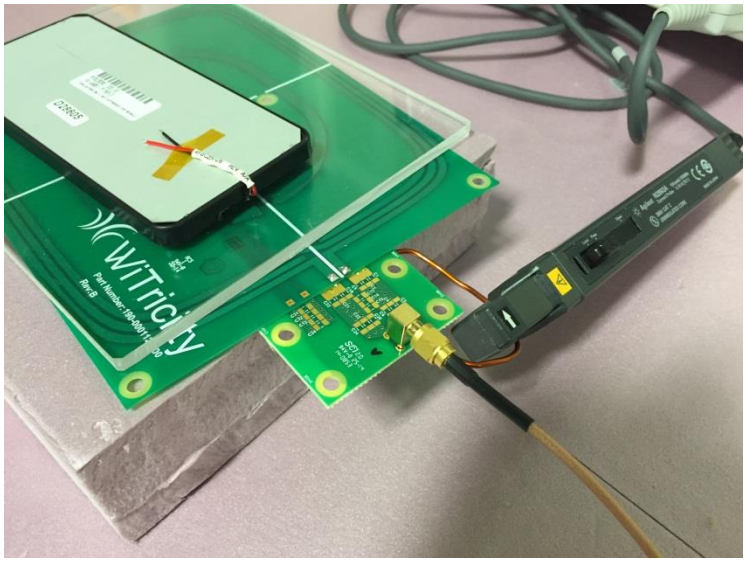
# A4WP System Overview



# Conformance and Non-conformance Measurements

*Using an Oscilloscope*

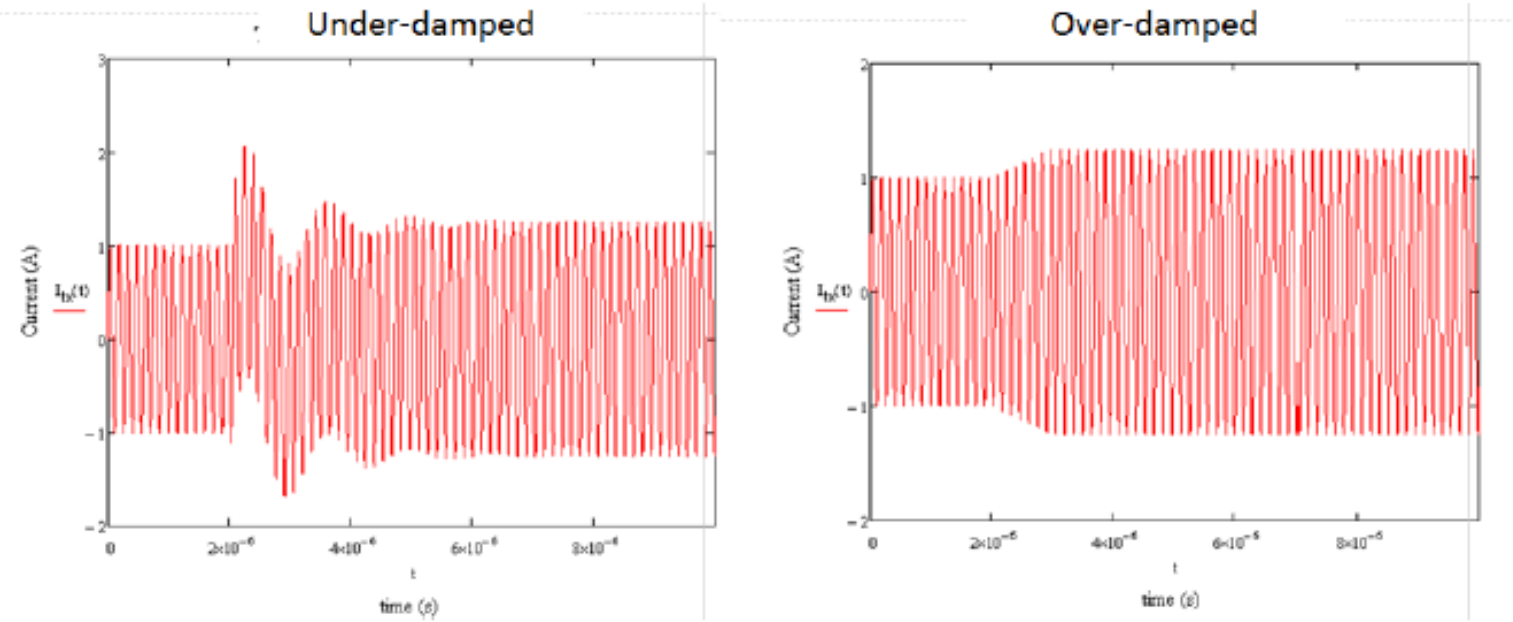
- Resonator Current ($I_{TX\_COIL}$)
  - Power Transfer State (Min, Max, Absolute max, Nominal, etc.)
  - Power Save State ($I_{TX\_SHORT\_BEACON\_MIN}$ & $I_{TX\_LONG\_BEACON\_MIN}$)
  - Resonator Frequency (6.78 MHz ±15 kHz)
  - Slew Rate (mArms/ms) & Settling Time
- Beacon Timing
  - $t_{SHORT\_BEACON}$
  - $t_{LONG\_BEACON}$
  - $t_{CYCLE}$
  - $t_{LONG\_BEACON\_PERIOD}$
- Power & Efficiency (*non-conformance*)
  - PTU Real Power ($P_{TX\_IN}$)
  - PRU Real Power ($P_{RX\_OUT}$)
  - Resonator Coupling Efficiency (RCE)
  - System Efficiency ($\eta = P_{RX\_OUT}/P_{IN(DC)}$)



# PTU Resonator Current Specifications

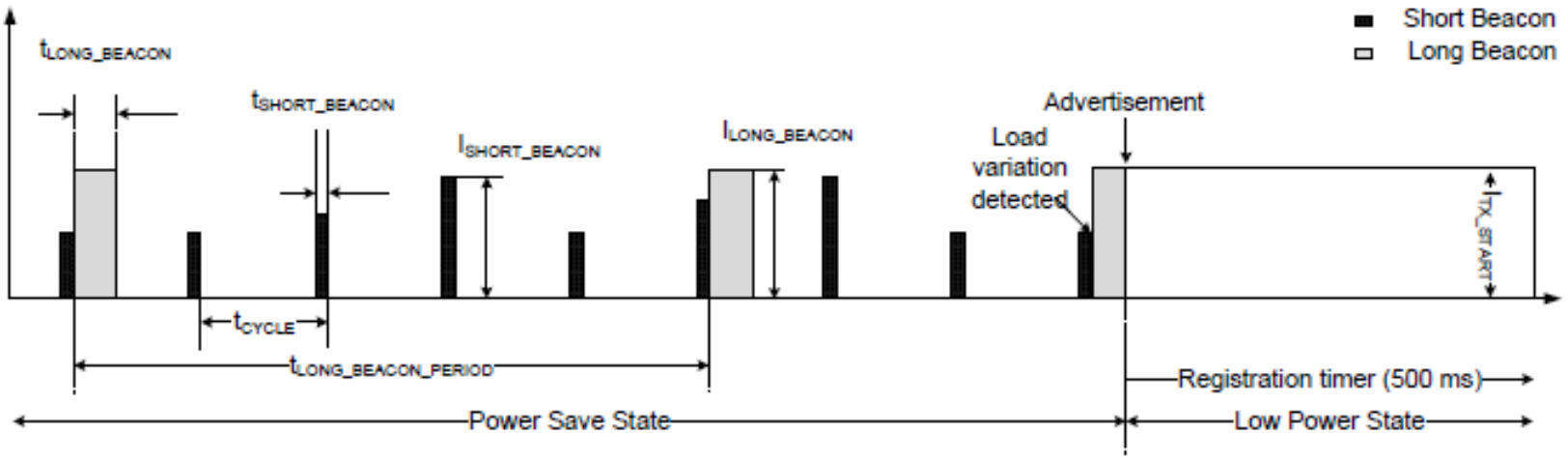
| Resonator Current ($I_{TX\_COIL}$) | Class 2 Example | Class 3 Example | Class 4 Example |
|---|---|---|---|
| $I_{TX\_MIN}$ | 410 mArms | 850 mArms | 965 mArms |
| $I_{TX\_SHORT\_BEACON\_MIN}$ | 410 mArms | 850 mArms | 600 mArms |
| $I_{TX\_LONG\_BEACON\_MIN}$ | 450 mArms | 850 mArms | 800 mArms |
| $I_{TX\_START}$ | 450 mArms | 850 mArms | 1300 mArms |
| $I_{TX\_NOMINAL}$ | 450 mArms | 1200 mArms | 1375 mArms |
| $I_{TX\_MAX}$ | 650 mArms | 1250 mArms | 1680 mArms |
| $I_{TX\_ABS\_MAX}$ | 750 mArms | 1300 mArms | 1862 mArms |
| SR-max($I_{TX}$) | 100 mArms/ms | 100 mArms/ms | 150 mArms/ms |

# PTU $I_{TX\_COIL}$ Transition Response & Slew Rate




- $I_{TX\_COIL}$ shall reach steady-state within 250 ms of any transition (90% of delta between start and end current values).
- Transition shall not be under-damped.
- Slew rate of $I_{TX\_COIL}$ (RMS current level change/shift - not instantaneous) shall not exceed SR-max ($I_{TX}$) unless faster rate is required to reach $I_{TX\_SHORT\_BEACON\_MIN}$ within 10ms.

# Beacon Timing and Sequence




| Time Contraint | Value (ms) | Description |
|---|---|---|
| $t_{SHORT\_BEACON}$ | 10 to 30 | The short beacon-on-period |
| $t_{LONG\_BEACON}$ | 105 ± 5 | The long beacon-on-period |
| $t_{CYCLE}$ | 250 ± 5 | The short beacon period |
| $t_{LONG\_BEACON\_PERIOD}$ | > 850 ≤ 3000 | The long beacon period |

# Resonate Coupling Efficiency (RCE)

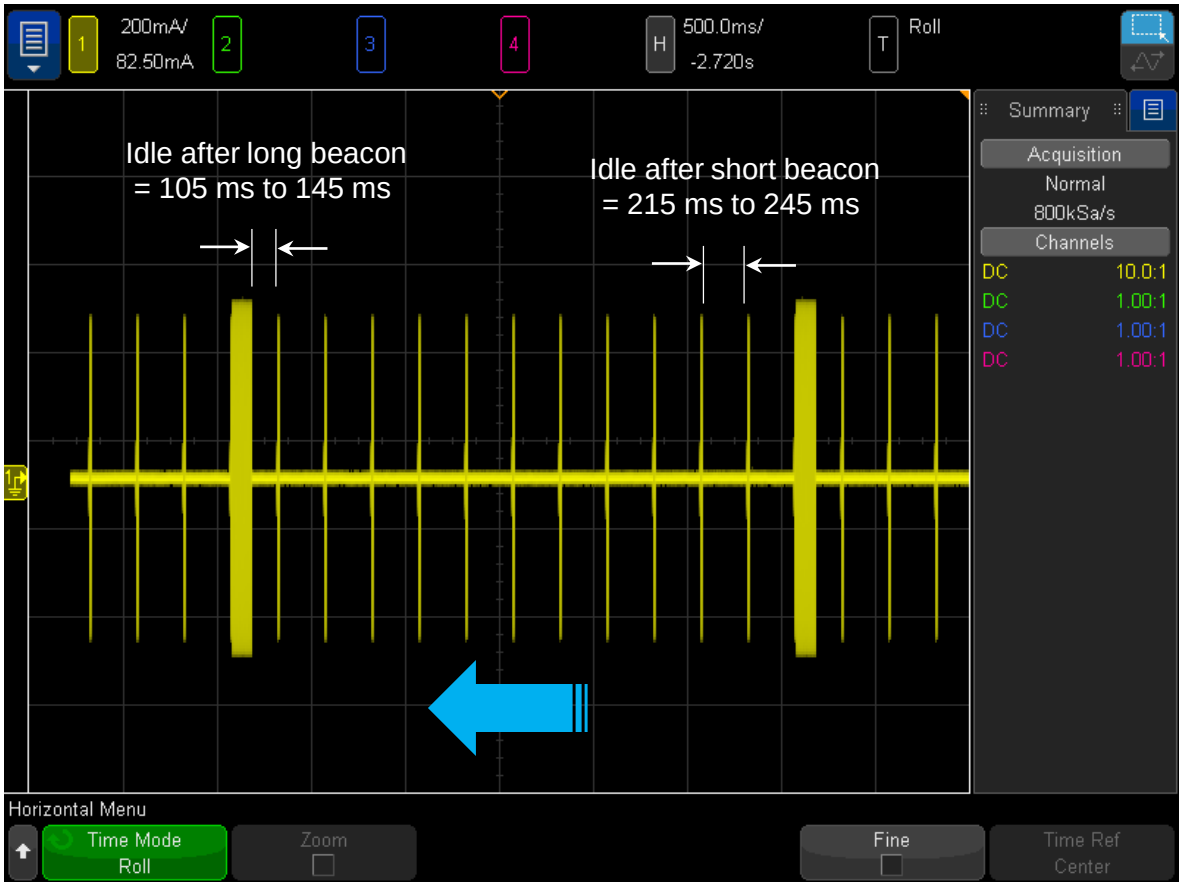
Minimum RCE (percent and dB) between PRU and PTU

*RCE stated as '% (dB)'*

| | Category 1 | Category 2 | Category 3 | Category 4 | Category 5 | Category 6 | Category 7 |
|---|---|---|---|---|---|---|---|
| Class 1 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Class 2 | N/A | 74 (-1,3) | 74 (-1,3) | N/A | N/A | N/A | N/A |
| Class 3 | N/A | 74 (-1,3) | 74 (-1,3) | 76 (-1,2) | N/A | N/A | N/A |
| Class 4 | N/A | 50 (-3) | 65 (-1,9) | 73 (-1,4) | 76 (-1,2) | N/A | N/A |
| Class 5 | N/A | 40 (-4) | 60 (-2,2) | 63 (-2) | 73 (-1,4) | 76 (-1,2) | N/A |
| Class 6 | N/A | 30 (-5,2) | 50 (-3) | 54 (-2,7) | 63 (-2) | 73 (-1,4) | 76 (-1,2) |

- For conformance testing, RCE is computed using S-parameters or Z-parameters obtained from network analyzer measurements.
- For design verification (non-conformance), RCE can be directly measured using an oscilloscope.
- At 6.78 MHz, probe deskew calibration is critical!
- Power losses and efficiency of various stages of the PTU and PRU can also be directly measured using an oscilloscope during design verification in order to optimize overall system efficiency.

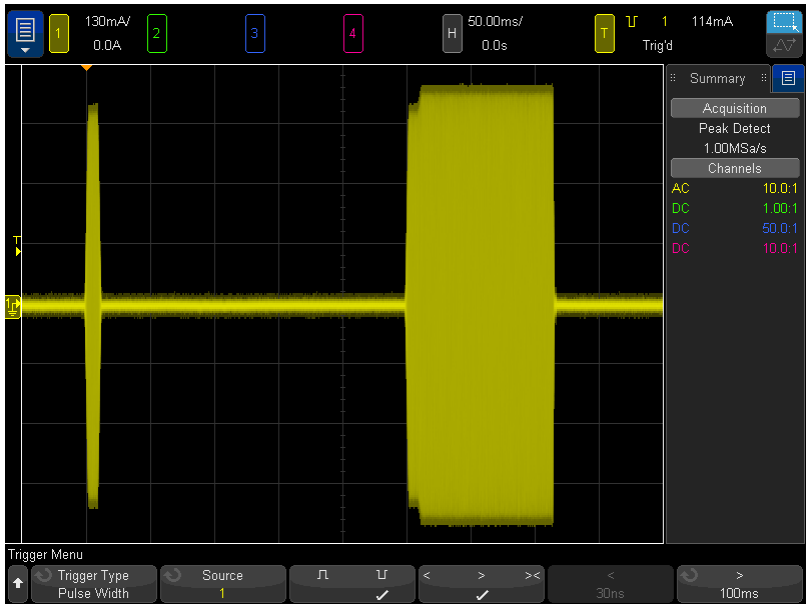
# Viewing Beacons in “Roll” mode



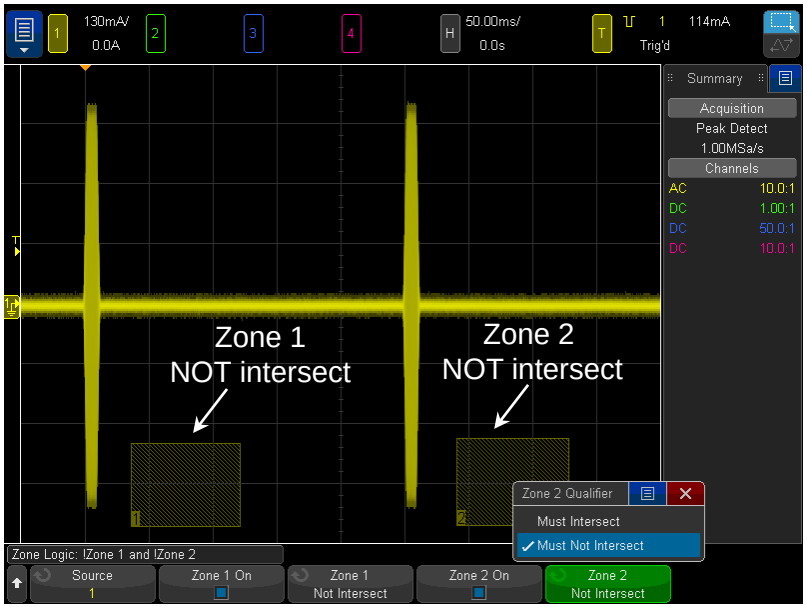

- Optimizing vertical scaling is easiest in “roll” mode.
- Although qualitative timing measurements can be performed using “roll” mode, precision quantitative timing AND current measurements should be performed in a triggered mode.

# Triggering on Isolated Short Beacons

*Without Zone Trigger*



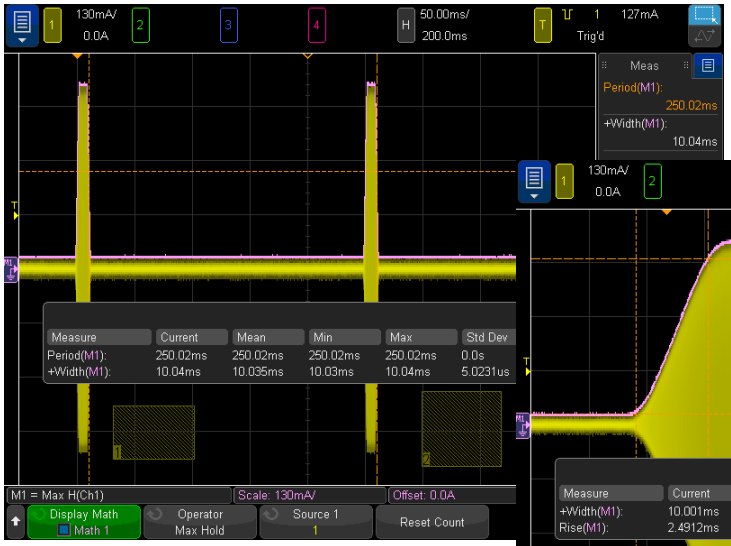

*With Zone Trigger*



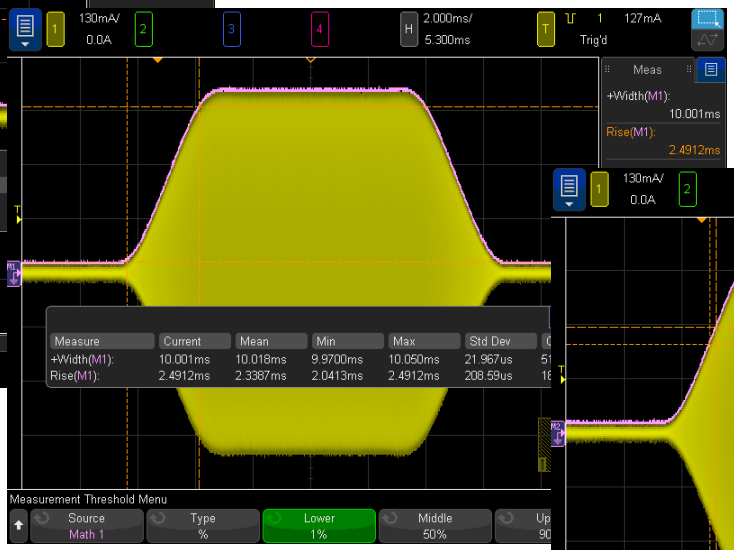

- Pulse Width (Low > 100 ns) triggers at the beginning of any short beacon (including short beacons concatenated with long beacons).
- *Zone Trigger* qualifies display and measurements on “isolated” short beacons.

# Short Beacon Timing Measurements

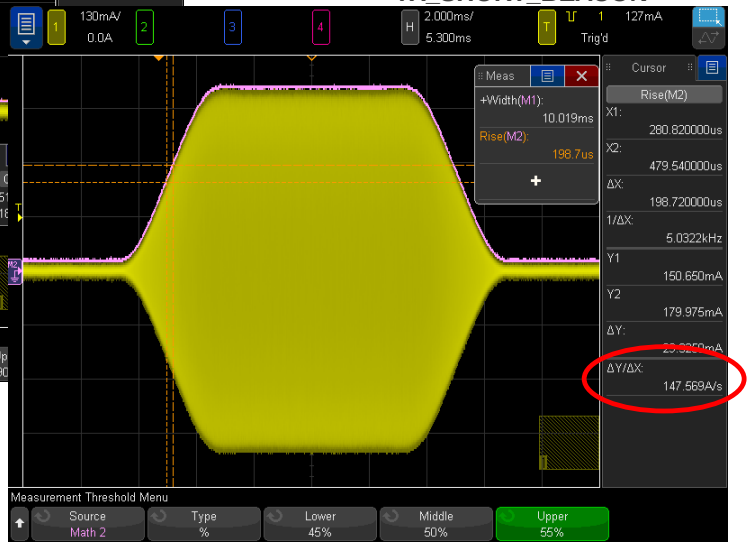
$t_{SHORT\_BEACON}$ & $t_{CYCLE}$




$t_{SETTLING}$ to 90%



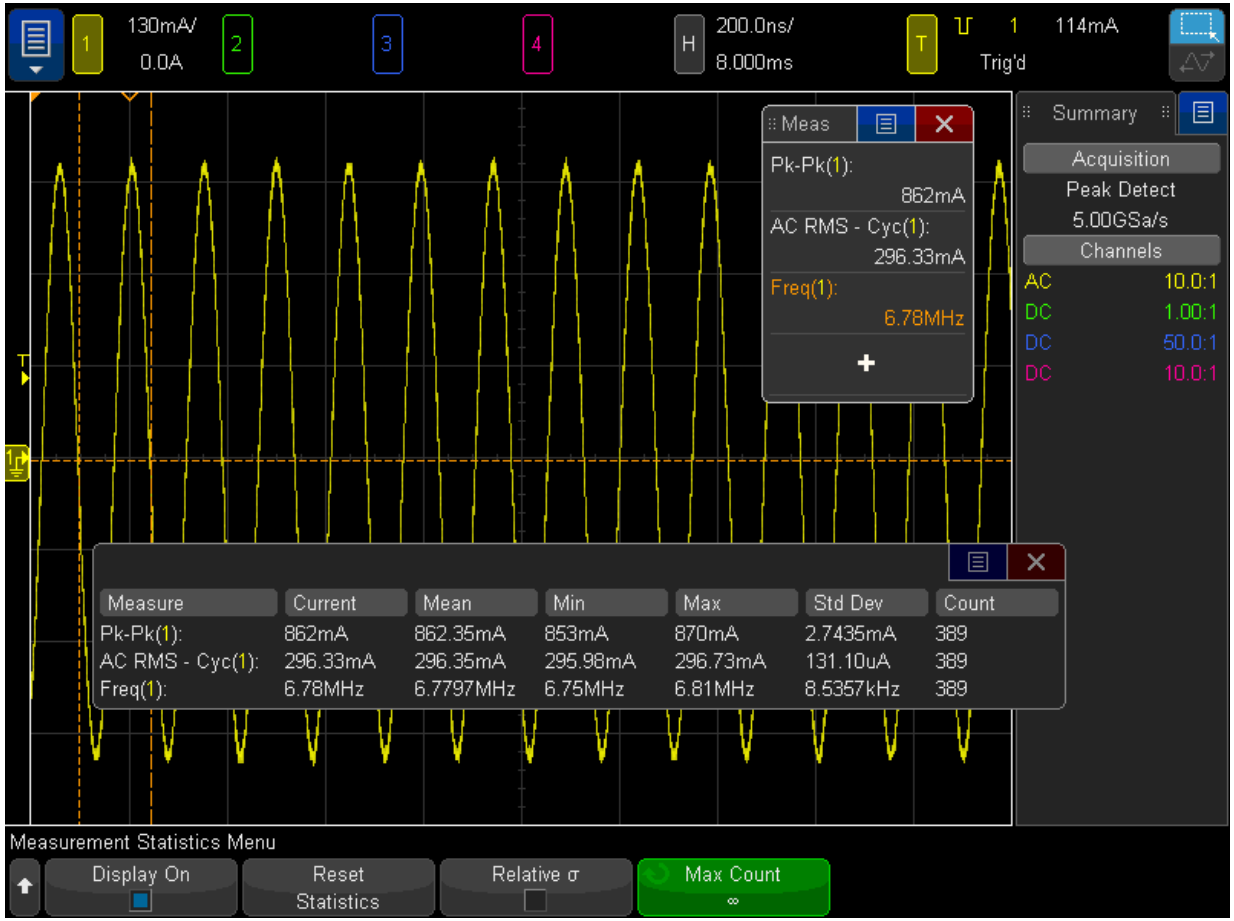

SR-max($i_{TX\_SHORT\_BEACON}$)




- "Max Hold" math function with Peak Detect acquisition mode plots positive peaks of beacons.
- Measurements (PW, Period, & Rise Time) performed on math function waveform.
- Custom threshold levels used to measure settling time and slew rate.

# Short Beacon Current & Frequency

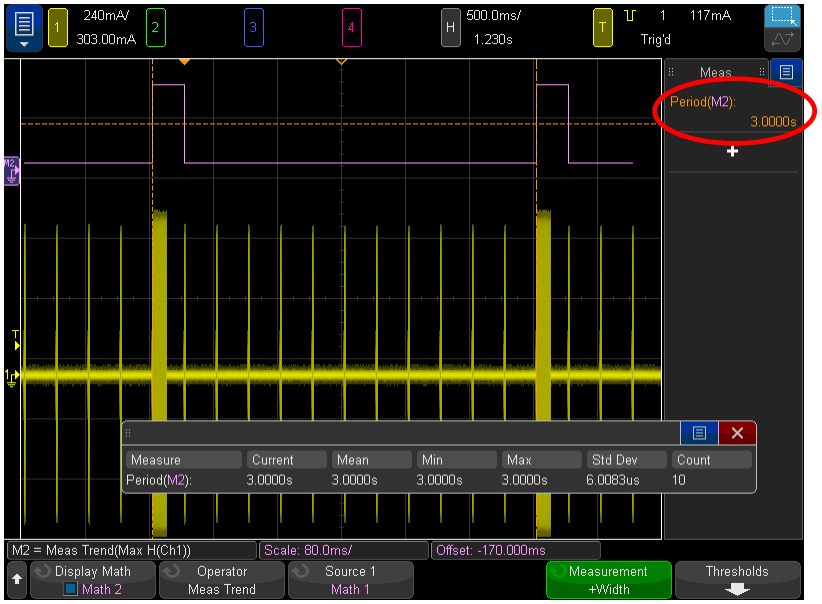
$I_{TX\_SHORT\_BEACON}$ 8 ms after beginning of short beacon




Note: Waveform averaging cannot be used due to phase jitter.

# Long Beacon Timing Measurements

$t_{LONG\_BEACON\_PERIOD}$




$t_{LONG\_BEACON}$


- "Max Hold" math function with Peak Detect acquisition mode plots positive peaks of beacons.
- PW "Measurement Trend" math function on "Max Hold" waveform plots long beacons

- "Max Hold" math function with Peak Detect acquisition mode plots positive peaks of beacons.
- Gated PW measurement on vertically expanded of "Smoothing" math function on "Max Hold" plots isolated long beacon IF there is a current level change between short and long beacons. Otherwise, measure short + long beacon width, then subtract short beacon.

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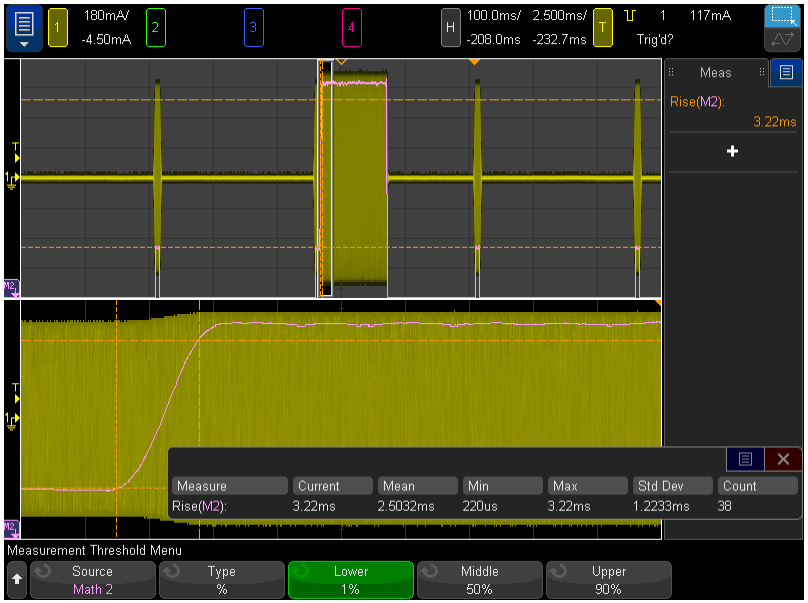
# Long Beacon Settling Time & Slew Rate

$i_{TX\_MAX\_SLEW}$

$t_{LONG\_BEACON\_SETTLING}$



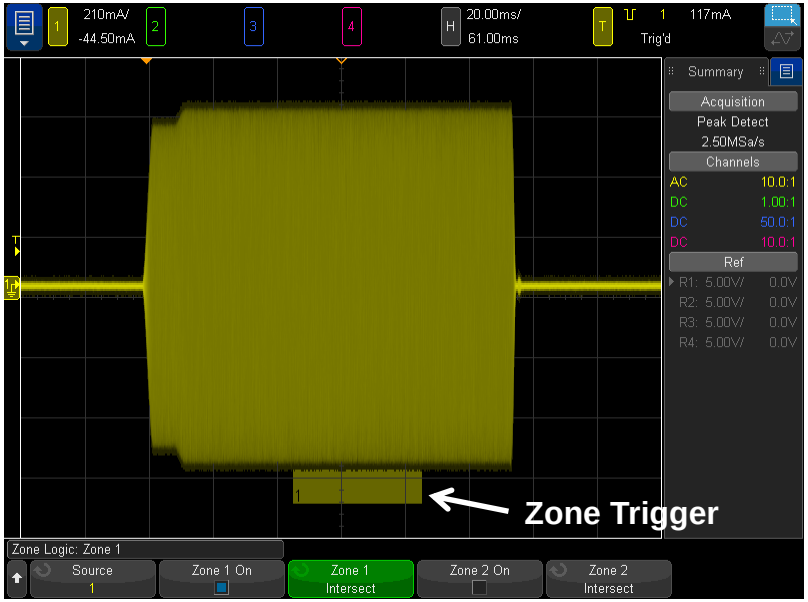

Gated rise time measurement (1% to 90%) on vertically expanded “Smoothing” math function that was applied to the “Max Hold” math function.

$SR\text{-}max(i_{TX\_LONG\_BEACON})$

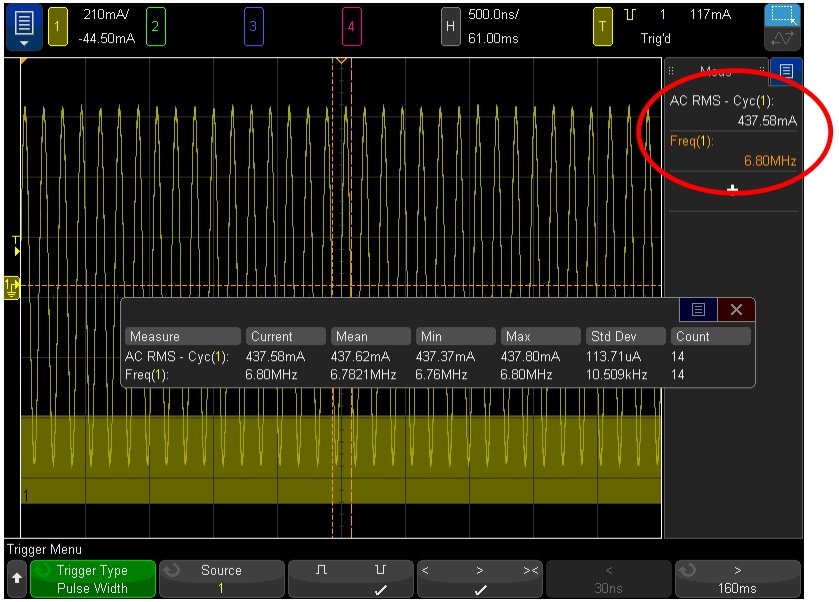

ΔY/ΔX (slew rate) cursor readout based on gated rise time measurement (45% to 55%) on Ax+B math function (rms scaling) that was applied to “Smoothing” math function that was applied to “Max Hold” math function.

# Long Beacon Current & Frequency

## Triggering on Long Beacons




## $I_{TX\_LONG\_BEACON}$

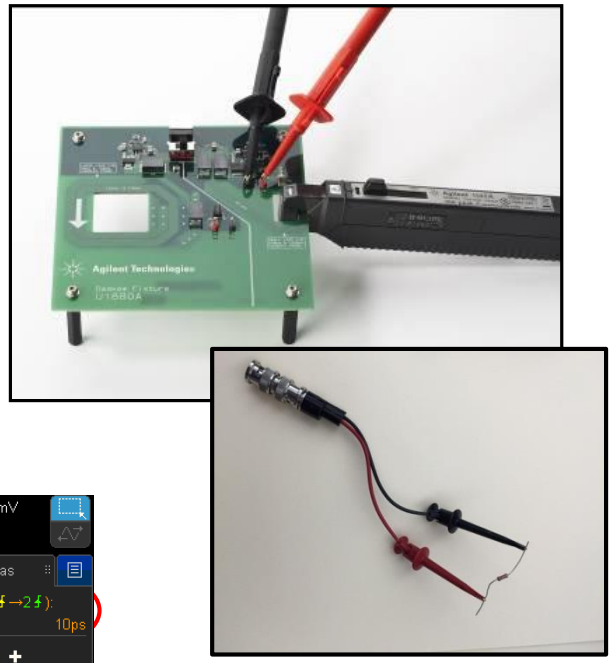



1. Trigger at the beginning of any short beacon using PW Trig = Low > 160 ms.
2. Qualify on concatenated short + long beacon using *Zone Trigger*.
3. Zoom-in horizontally after long beacon settling to measure RMS current and frequency.

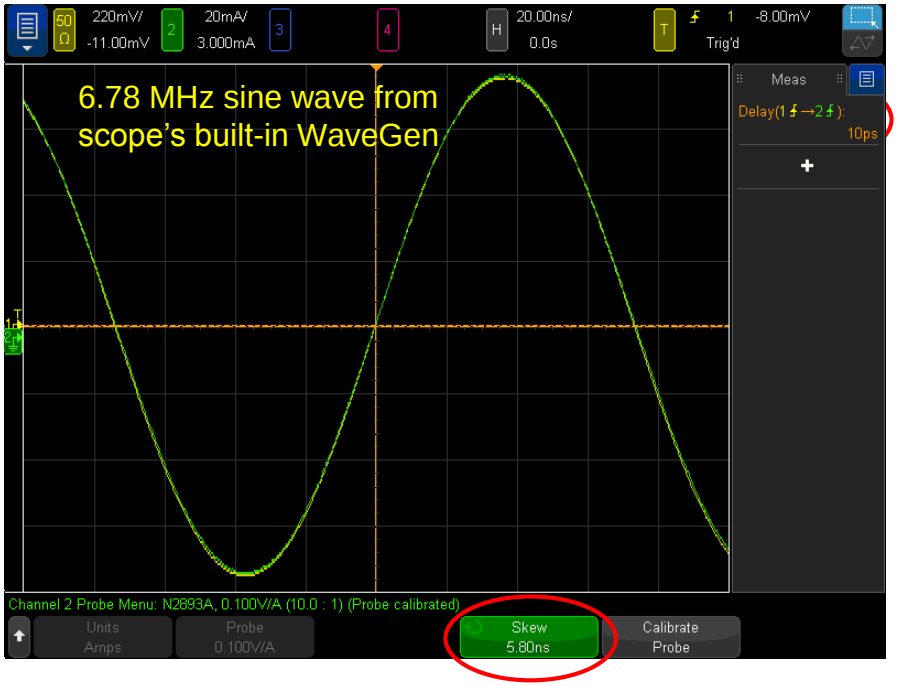
Note: Waveform averaging cannot be used due to phase jitter.

# Resonator AC Power & Efficiency Measurements

- De-skewing is critical to ensure accurate power (V x I) measurements!
- The de-skew fixture (or a 10-Ω resistor) along with the power option automatically calibrates the time delay between voltage and current probe to insure accurate power loss measurements.



**Deskewed!**



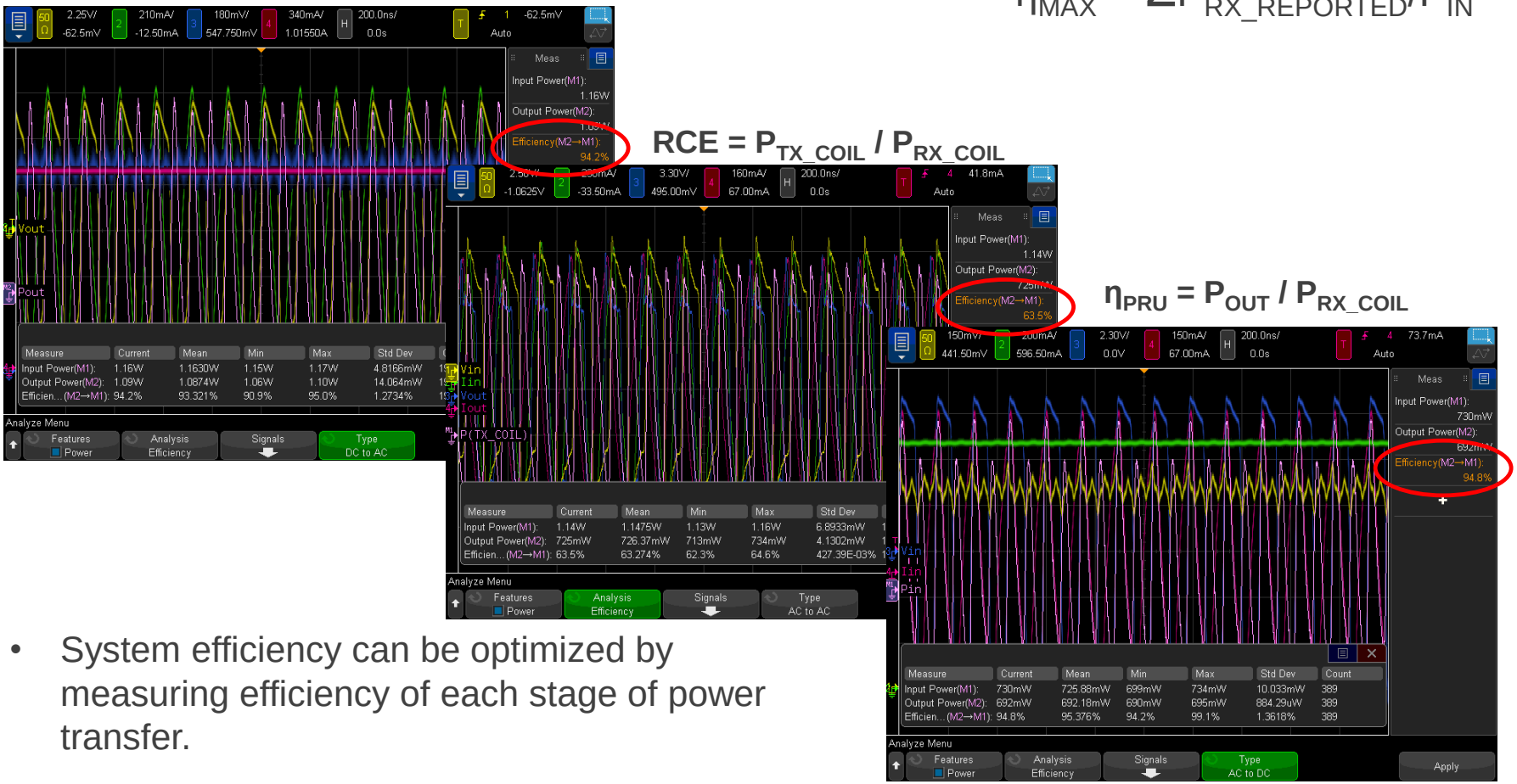
# Efficiency Measurements (η)

$\eta_{PTU} = P_{IN} / P_{TX\_COIL}$

$\eta_{MAX} = \sum P_{RX\_REPORTED} / P_{IN}$

$RCE = P_{TX\_COIL} / P_{RX\_COIL}$

$\eta_{PRU} = P_{OUT} / P_{RX\_COIL}$




- System efficiency can be optimized by measuring efficiency of each stage of power transfer.
- InfiniiVision oscilloscope's power app option automates probe deskew and efficiency measurements.

# Recommended Probes

- AC/DC current probes
  - **N2893A 100MHz, 30Apk[1]**
  - **1147B 50MHz, 30Apk[1]**
  - N2780B 2MHz, 700Apk (requires N2779A power supply)
  - N2781B 10MHz, 300Apk (requires N2779A power supply)
  - N2782B 50MHz, 50Apk (requires N2779A power supply)
  - N2783B 100MHz, 50Apk (requires N2779A power supply)
  - N2820A 2-ch high-sensitivity (50µA/500kHz to 5A/3MHz)
- HV differential active probes
  - N2804A 300MHz, ± 300V, 100:1, 4MΩ/4pF
  - N2805A 200MHz, ± 100V, 50:1, 4MΩ/4pF
  - **N2818A 200MHz, ± 20V, 10:1, 1MΩ/3.5pF**
  - **N2790A 100MHz, ± 1.4kV, 50:1 or 500:1, 8MΩ/3.5pF**
  - N2891A 70MHz, ± 7kV, 100:1 or 1000:1, 100MΩ/5pF
  - N2791A 25MHz, ± 700V, 10:1 or 100:1, 8MΩ/8pF
- Passive probes
  - **N2894A, 700MHz, ±200V, 10:1,10MΩ/9.5pF (standard)**
  - 10076C, 500MHz, ± 4kV,100:1, 67MΩ/3pF
  - N2870A 35MHz, 1:1 (for output ripple), 1MΩ/39pF
  - 10070D 20MHz, 1:1 (for output ripple), 1MΩ/70pF
- Single-ended active probe (for measuring output ripple)
  - N7020A, 2GHz, 1:1, ± 24 V offset, 50kΩ (DC)

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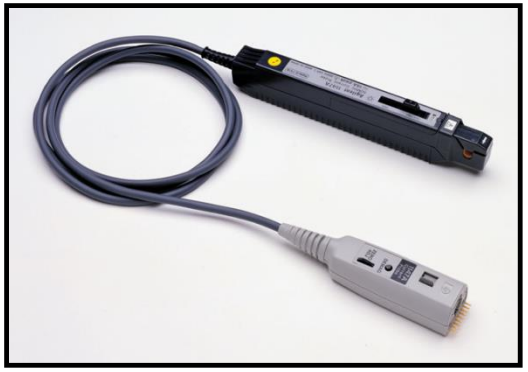
Notes

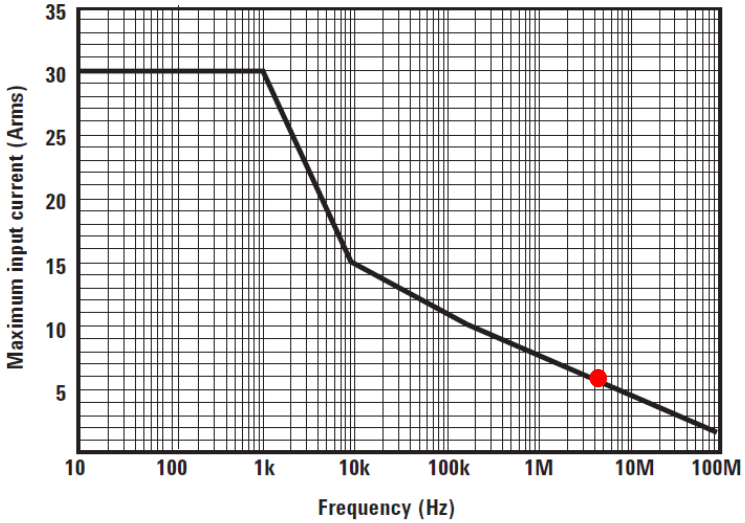
1. 15A peak max current if two probes connected to scope.

# Selecting the Right Current Probe

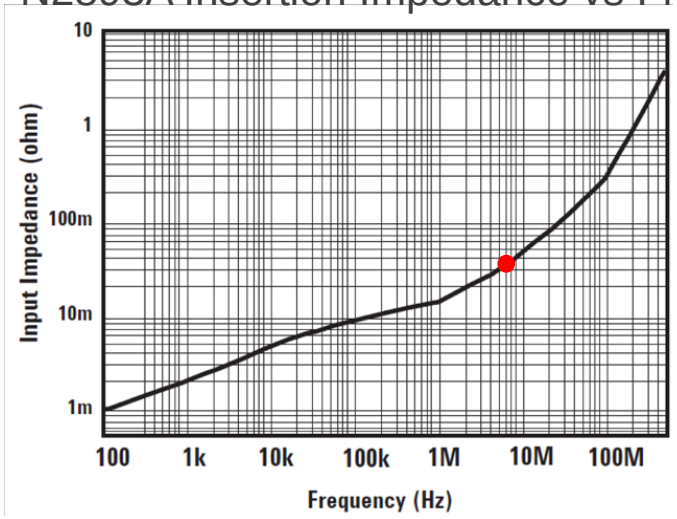
| Model | Bandwidth | Max Peak Current (AC + DC) | Conversion Factor | Insertion Impedance @ 6.78 MHz | Max Current @ 6.78 MHz |
|---|---|---|---|---|---|
| **1147B** | 50 MHz | 30 A[1] | 0.1 V/A | 600-mΩ | ~3.5 A-RMS |
| **N2893A** | 100 MHz | 30 A[1] | 0.1 V/A | 40-mΩ | ~5 A-RMS |



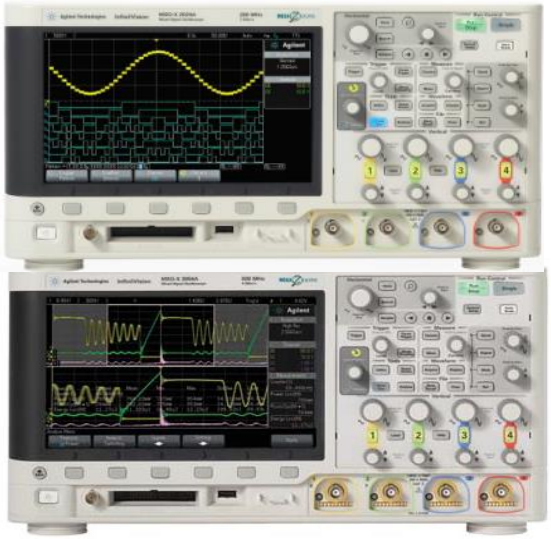
N2893A De-rate Current vs Freq




N2893A Insertion Impedance vs Freq



# Keysight InfiniiVision X-Series Oscilloscopes



www.keysight.com/find/InfiniiVision


| | Bandwidth | Sample Rate | Mem (max) | Seg Mem | Update Rate | MSO Option | Zone Trig | Power Option |
|---|---|---|---|---|---|---|---|---|
| 2000X | 70 to 200 MHz | 2 GSa/s | 1M | Option | 50k/sec | 8-ch | No | No |
| 3000X 3000T | 100 MHz to 1 GHz | 4 GSa/s, 5 GSa/s | 4M | Option | 1M/sec | 16-Ch | No | Yes* |
| 4000X | 200 MHz to 1.5 GHz | 5 GSa/s | 4M | Std | 1M/sec | 16-Ch | Yes | Yes |
| 6000X | 1 GHz to 6 GHz | 20 GSa/s | 4M | Std | 450k/sec | 16-Ch | Yes | Yes |

# FREE InfiniiVision X-Series Application Bundles

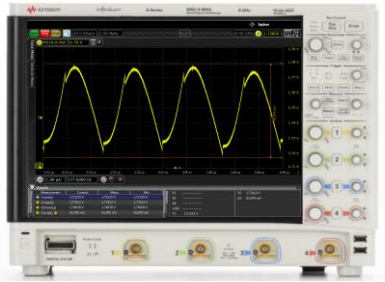
Available June 1 - Nov 30, 2015

Receive a **free** application bundle when you purchase a Keysight InfiniiVision 2000 X, 3000A/T X, 4000 X or 6000 X-Series oscilloscope! This incredible value enables all of the software options available and will fully-equip your next scope purchase.

| | 2000 X-Series | 3000 X-Series | New 3000 T-Series | 4000 X-Series | 6000 X-Series |
|---|---|---|---|---|---|
| **Option Number** | DSOX2APPBNDL | DSOX3APPBNDL | DSOXT3APPBNDL | DSOX4APPBNDL | DSOX6APPBNDL |
| **App Bundle US$** | **$1,250** | **$2,750** | **$2,750** | **$1,500** | **$4,650** |
| **Total Value US$** | **$ 3,422** | **$13, 165** | **$12,711** | **$18,449** | **$23,831** |
| Application software enabled | DSOX2WAVEGEN | DSOX3WAVEGEN | DSOX3WAVEGEN | DSOX4WAVEGEN2 | DSOX6WAVEGEN2 |
| | DSOX2AUTO | DSOX3ADVMATH | DSOX3AERO | DSOX4AERO | DSOXDVMCTR |
| | DSOX2COMP | DSOX3AERO | DSOX3AUDIO | DSOX4AUDIO | DSOX6JITTER |
| | DSOX2EMBD | DSOX3AUDIO | DSOX3TAUTO | DSOX4AUTO | DSOX6PWR |
| | DSOX2MASK | DSOX3AUTO | DSOX3COMP | DSOX4COMP | DSOX6MASK |
| | DSOX2MEMUP | DSOX3COMP | DSOX3EMBD | DSOX4EMBD | DSOX6USBSQ |
| | DSOX2SGM | DSOX3EMBD | DSOX3FLEX | DSOX4FLEX | DSOX6VID |
| | DSOXDVM | DSOX3FLEX | DSOX3MASK | DSOX4FPGAX | DSOX6FPGAX |
| | DSOXEDK | DSOX3MEMUP | DSOX3PWR | DSOX4MASK | DSOXEDK |
| | | DSOX3MASK | DSOX3VID | DSOX4PWR | DSOX6EMBD |
| | | DSOX3PWR | DSOXT3DVMCTR | DSOX4USBFL | DSOX6COMP |
| | | DSOX3SGM | DSOXEDK | DSOX4USBH | DSOX6USBFL |
| | | DSOX3VID | DSOXT3SENSOR | DSOX4USBSQ | DSOX6USBH |
| | | DSOXDVM | | DSOX4VID | DSOX6AUTO |
| | | DSOXEDK | | DSOXDVM | DSOX6FLEX |
| | | | | DSOXEDK | DSOX6AUDIO |
| | | | | DSOX4SENSOR | DSOX6AERO |

*Bundles include listed options only. Does not include MSO or bandwidth upgrades option. No promotion number required. Prices subject to change.

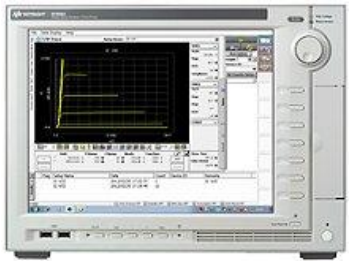
# Keysight products for characterizing power supplies



InfiniiVision & Infiniium S-Series Oscilloscopes


PA2201A IntegraVision AC Power Analyzer

E5061B Network Analyzer



B1506A Power Device Analyzer

N6705B DC Power Analyzer

# Thank you for your attendance!