Keysight Technologies

Alliance for Wireless Power (A4WP) Measurements Using an Oscilloscope (Part 2)

I_{TX_COIL} Measurements during the Power Save State (Beacons)

Application Note

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Introduction

One of the primary instruments used when designing and testing A4WP compliant wireless charging products is an oscilloscope. Although many of the required conformance test measurements may be relatively easy to perform during the power transfer state when current is continuous, performing many of the timing and current measurements during the power save state (beacons) can be much more complex. There are many advanced oscilloscope settings and measurements that you may not be aware of that makes these measurements possible and will also provide enhanced accuracy and repeatability of A4WP oscilloscope measurements.

This application note is Part 2 of a 3-part series on A4WP wireless charging measurements. This part focuses on performing I_{TX_COIL} measurements during the power save state (beacons), including beacon timing measurements. Part 1 focuses on I_{TX_COIL} measurements during the power transfer state (non-beacons), and Part 3 focuses on power and efficiency measurements. Refer to Part 1 and Part 3 for additional A4WP testing information.

This application note provides step-by-step instructions based on using a Keysight InfiniiVision X-Series oscilloscope. Note that each individual measurement builds upon the previously documented measurement.

The following A4WP power save state (beacons) measurements and topics are covered in this document:

- Optimizing Vertical Scaling
- Short Beacon Measurements
  - Short-beacon-on Period ($t_{SHORT\text{-}BEACON}$)
  - Short Beacon Period (t_{CYCLE})
  - Short Beacon Transition Settling Time
  - Short Beacon Slew Rate
  - Short Beacon RMS Current ($I_{TX\_SHORT\_BEACON}$) and Frequency
- Long Beacon Measurements
  - Long-beacon-on Period ($t_{LONG\text{-}BEACON}$)
  - Long Beacon Transition Settling Time
  - Long Beacon Slew Rate
  - Long Beacon RMS Current ($I_{TX\_LONG\_BEACON}$) and Frequency
  - Long Beacon Period ($t_{LONG\_BEACON\_PERIOD}$)
- Selecting the Right Current Probe

Optimizing Vertical Scaling

Performing measurements on long and short beacons requires that you first optimize vertical scaling of the I_{TX_COIL} waveform. Unfortunately, using the scope's AutoScale feature is not reliable when capturing very low duty cycle burst-type signals such as I_{TX_COIL} beacons.

For beacon timing measurements, most engineers put the scope into its horizontal "roll" mode on a slow timebase range, such as 50 ms/div or slower, and then manually adjust the scope's vertical scaling (A/div) based on visual judgments. In "roll" mode, incoming signals (I_{TX_COIL} beacons in this case) are captured in real-time without triggering. Waveforms scroll (or roll) across the scope's display from right to left. Figure 1 shows an example of capturing I_{TX_COIL} with a long beacon cycle time of 1000 ms in the scope's roll mode at 200 ms/div (2 seconds across screen).

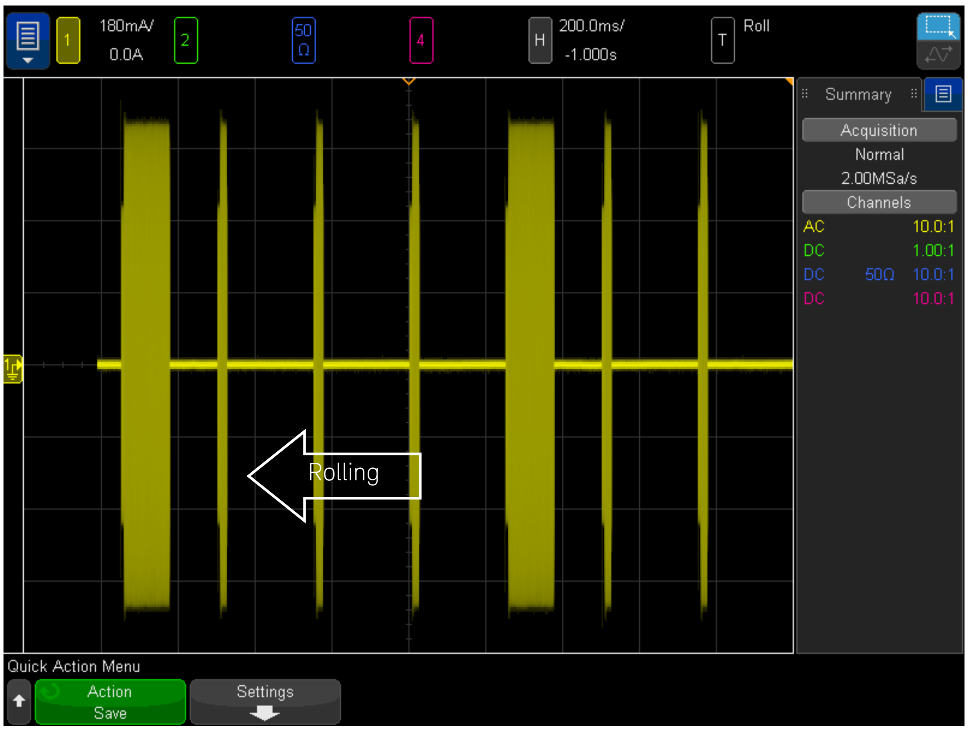

Figure 1. Using the scope's roll mode to observe I_{TX_COIL} beacons.

To perform timing measurements, such as the width and/or cycle time of long beacons or short beacons, engineers typically stop oscilloscope acquisitions when they see the waveform pattern that they are looking for, and then manually position timing cursors on the waveform. This measurement technique can't be automated, provides low resolution measurement results, and is prone to errors. In addition, performing measurements within a narrow slice of a beacon such as the slew rate, RMS current, and/or frequency of the beacon, while capturing the waveform on a slow timebase range in roll mode, is impossible.

All of the required beacon measurements can be automated and performed with maximum measurement resolution and accuracy using a variety of specialty triggering modes, waveform math functions, and measurements available in Keysight's InfiniiVision X-Series oscilloscopes. Begin by connecting a Hall-effect current probe, such as Keysight's N2893A or 1147B, to one of the scope's input channels (typically channel-1). Calibrate the current probe (offset and de-gauss). Refer to Appendix A for additional details concerning current probe calibration. Next, connect the current probe to the PTU's I_{TX_COIL} signal while in the power save mode (beacons), then following these instructions (manually or under programmed control) to optimize vertical scaling (without using *AutoScale*).

1. *Default Setup*.
2. Set input coupling of I_{TX_COIL} channel (typically channel-1) to AC.
3. Set vertical scaling of I_{TX_COIL} to 2 A/div.
4. Select Horizontal *Roll* mode (Horizontal menu).
5. Select the *Peak Detect* acquisition mode (Acquire menu).
6. Set timebase to 500 ms/div.
7. If setting up the scope manually, adjust vertical scaling until the waveform is vertically spread across an approximate 7 divisions peak-to-peak. Note that if you press the vertical scaling knob, you can toggle between coarse and fine scale factors.
8. If automating under computer control, measure the peak-to-peak current level at the initial setting of 2A/div, then re-scale the vertical A/div setting for approximately 4 divisions peak-to-peak based on this measurement (A/div setting = I_{TX_COIL} p-p/4).
9. Repeat step #8 for approximately 7 divisions peak-to-peak (A/div setting = I_{TX_COIL} p-p/7).

Short Beacon Period (t_{CYCLE})

After you have optimized vertical scaling of the scope's input channel (typically channel-1), making various timing and current measurements during short beacons requires that you set up the scope to trigger on isolated short beacons. In other words, short beacons that are NOT concatenated with long beacons. This can be achieved by using the scope's pulse-width trigger mode to trigger on any short beacon, including those concatenated with long beacons, and then use the scope's *Zone Trigger* capability to qualify on isolated short beacons. To measure short-beacon-on period (t_{CYCLE}), continue with the following steps:

10. Change Horizontal Time Mode from *Roll* to *Normal* (Horizontal menu).
11. Set timebase to 50 ms/div with Delay/horizontal position = +200 msec.
12. Set trigger mode to *Normal* (Trigger Mode/Coupling menu).
13. Set trigger source to I_{TX_COIL} channel (defaults to channel-1).
14. Turn on *Noise Reject* (Trigger Mode/Coupling menu).
15. Set trigger level approximately 1 division above idle level. If automating, trigger level should be set to the same setting as the final vertical A/div setting. For example, if the A/div setting is 500 mA/div, then set the trigger level to +500 mA.
16. Select *Pulse Width* triggering based on the following criteria:
    - Source = I_{TX_COIL} channel (typically channel-1)
    - Pulse polarity = Negative
    - Time qualification: > 100 ms

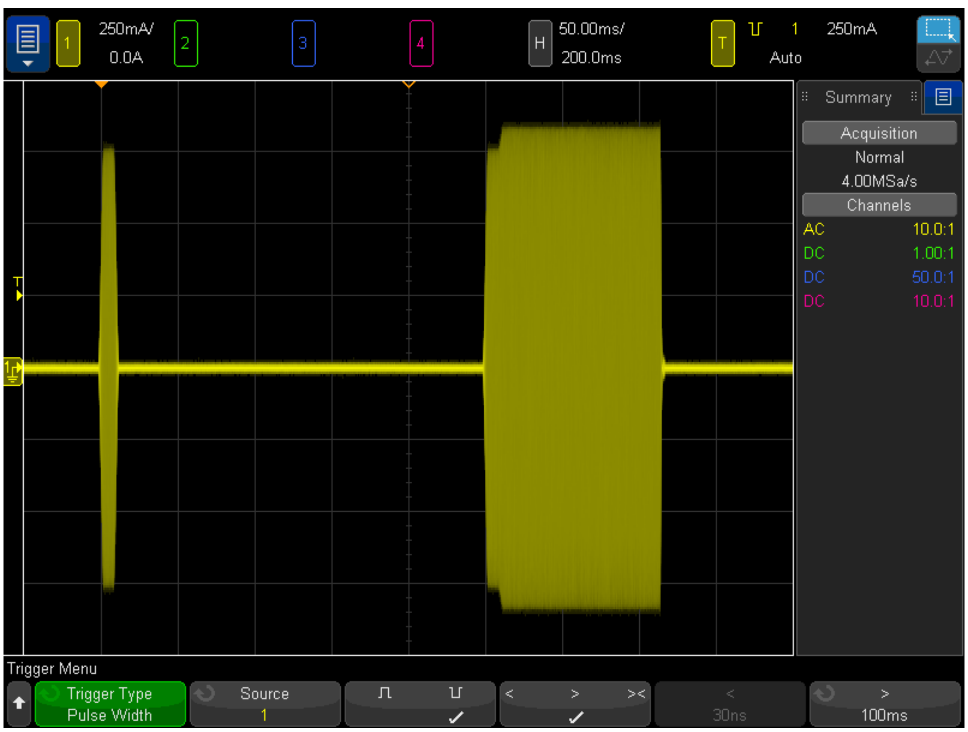

Figure 2: Using Pulse-width triggering to synchronize on any short beacon, including short beacons concatenated with long beacons.

Your scope should now be triggering at the beginning of any short beacon, including short beacons that may be concatenated with long beacons as shown in Figure 2. We can now use *Zone Trigger* to disqualify any acquisitions that contain a long beacon. Continue with the following steps:

17. Using the scope's touch-screen, create a zone box (Zone1) approximately 30 ms after the beginning of the 1st short beacon and below the idle level.
18. Select "Must Not Intersect" for Zone1.
19. Create another zone box (Zone2) approximately 30 ms after the beginning of the 2nd short beacon and below the idle level.
20. Select "must not intersect" for Zone2.

Your scope should now display two isolated short beacons as shown in Figure 3. If you are automating this set up procedure under computer control using SCPI commands, the two zone box regions can be defined based on height, width, and position. To learn more about *Zone Trigger*, refer to the application note listed at the end of this document.

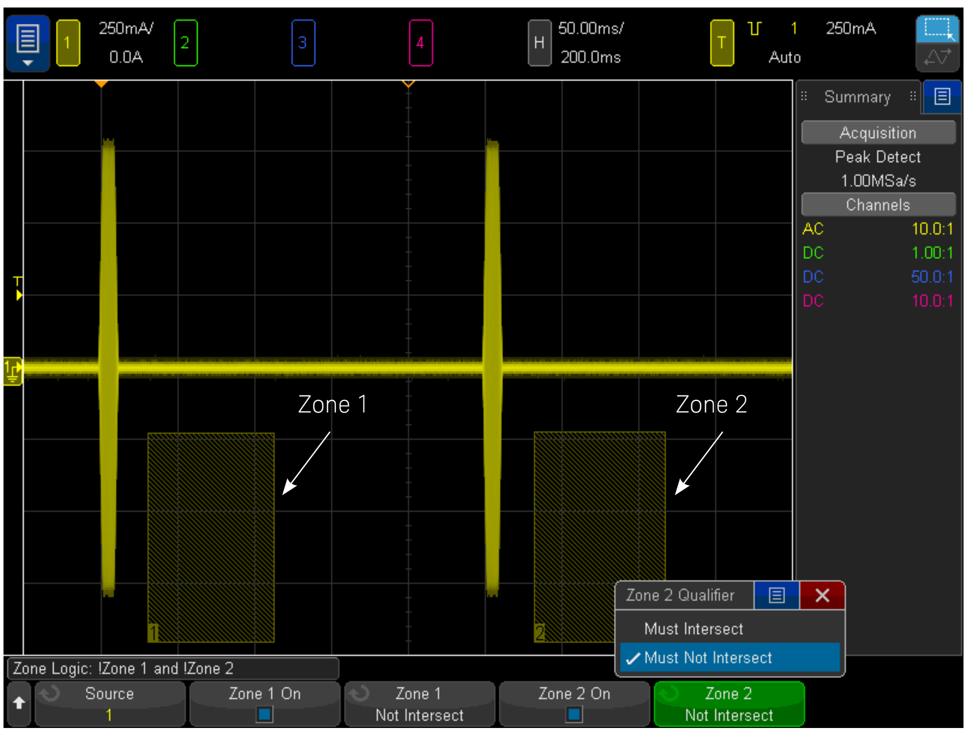

Figure 3. Isolating non-concatenated short beacons using Zone Trigger.

To measure the short beacon cycle time (t_{CYCLE}), we will turn on the scope's *Max Hold* waveform math function, and then perform required measurements on that waveform. Continue with the following steps:

21. Turn on the Math1 waveform math function based on the following criteria:
   - Operator = MAX HOLD
   - Source = I_{TX_COIL} channel
   - Set Math1 vertical scaling equal to the I_{TX_COIL} channel's vertical scaling.
22. Select the *Period* measurement on Source = Math1.

Figure 4 shows the measurement results. The scope's *Max Hold* waveform math function (purple waveform riding on top of I_{TX_COIL}) plots the positive extremes of I_{TX_COIL}. This math function creates a waveform that looks like pulses the width of each short beacon.

The scope's *Period* measurement on the *Max Hold* waveform measures the cycle time of short beacons (t_{CYCLE}), which must be 250 ms ±5 ms. At this setting, the scope provides 10 µs of measurement resolution.

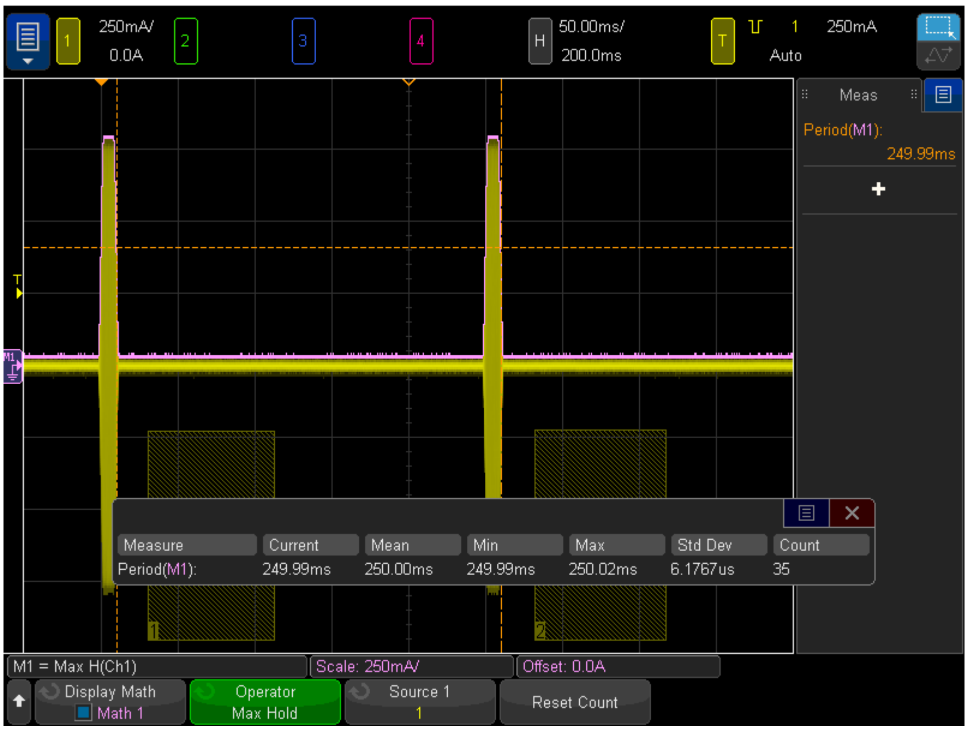

Figure 4. Measuring t_{CYCLE} (short beacon period) using the scope's Max Hold waveform math function and a Period measurement.

Short-beacon-on Period (t_{SHORT_BEACON})

Although we could also measure the width of the short beacon burst (t_{SHORT_BEACON}) at the same timebase setting that was used in the previous t_{CYCLE} measurement (50 ms/div), we can obtain a higher resolution and more accurate measurement of t_{SHORT_BEACON} if we zoom-in closer on just a single short beacon. To measure t_{SHORT_BEACON}, continue with the following steps:

23. Change timebase setting to 5 ms/div with the Delay/horizontal position = +20 ms.
24. Select the +*Width* measurement on Source = Math1.

Figure 5 shows the results of the t_{SHORT_BEACON} measurement, which must be between 10 ms and 30 ms. In this measurement example t_{SHORT_BEACON} measured 10.002 ms.

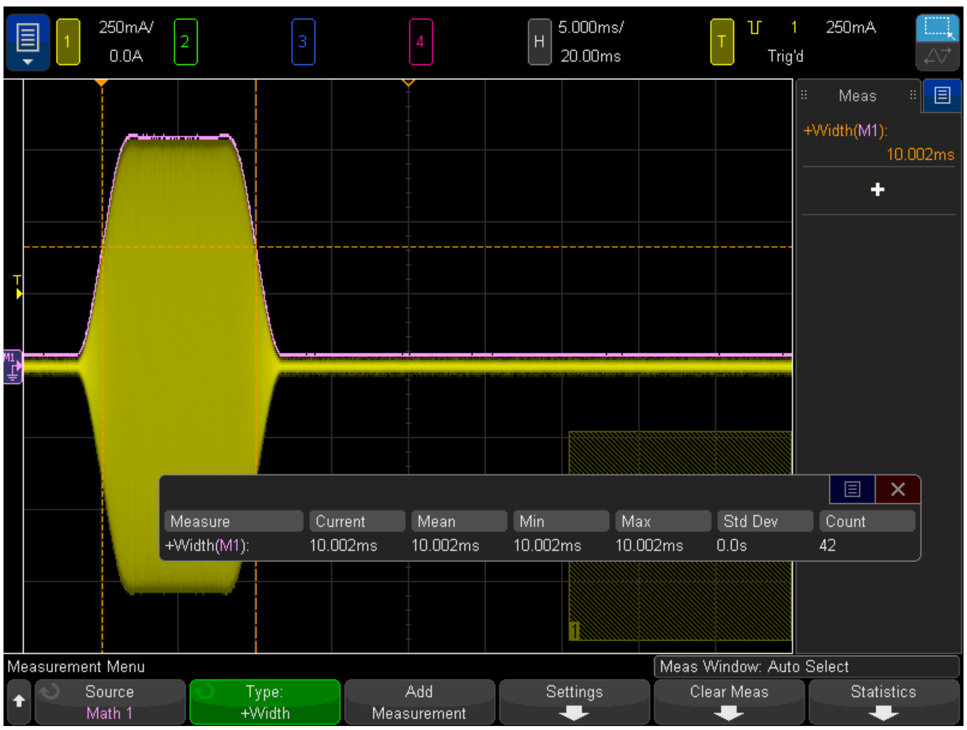

Figure 5. Measuring the short beacon width (t_{SHORT_BEACON}) using the scope's +Width measurements on the Max Hold math waveform.

Short Beacon Transition Settling Time of I_{TX_COIL}

Short beacon transition settling time is the time it takes for short beacons to increase from the idle current level to 90% of the steady-state current level. This time can be measured using the scope's *Rise Time* measurement on the *Max Hold* waveform based on custom measurement threshold levels. To measure short beacon transition settling time, continue with the following steps:

25. Select the *Rise Time* measurement on Source = I_{TX_COIL} channel.
26. Change Math1 lower measurement threshold level to 1%.

The default lower measurement threshold level for rise time measurements is 10%, while the default upper level is 90%. By changing the lower measurement threshold level to 1%, the rise time measurement on the *Max Hold* waveform will provide the required transition settling time measurement of I_{TX_COIL} from 1% to 90% as shown in Figure 6. In this example the transition settling time measured approximately 2.54 ms. Although the maximum specified transition settling time is for current to reach 90% of its steady-state level within 250 ms, for short beacons the maximum settling time is 10 ms, which is also the minimum short-beacon-on period.

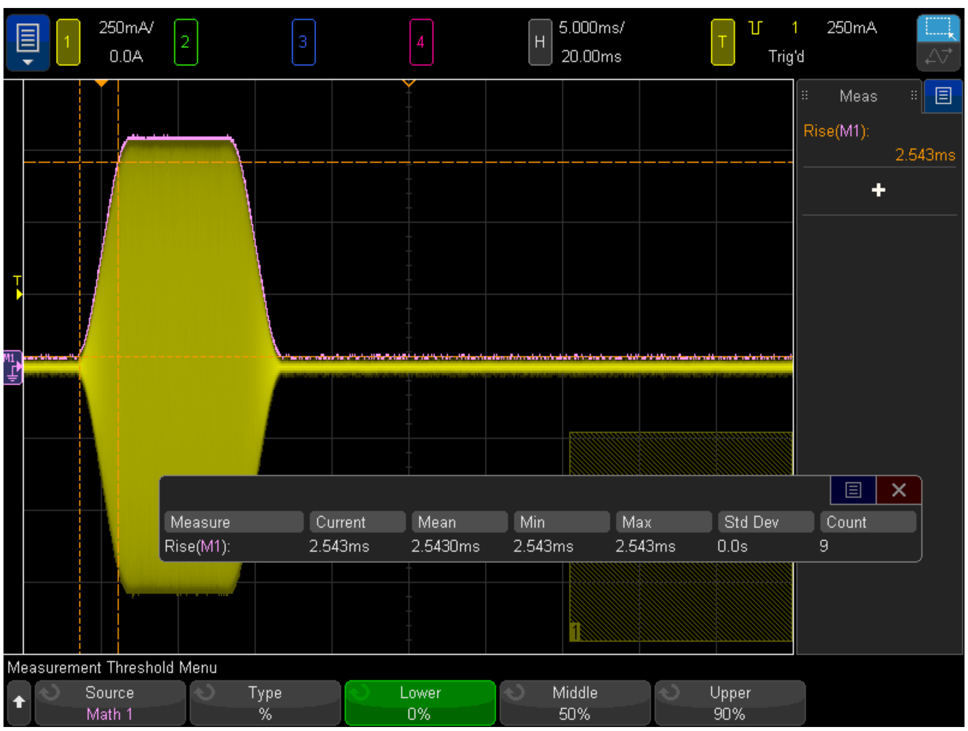

Figure 6. Measuring the transition settling time of a short beacon.

Short Beacon Slew Rate of I_{TX_COIL}

The Slew Rate of the current level change can be measured by simply changing the measurement threshold levels for the previously selected *Rise Time* measurement to 45% (lower threshold) to 55% (upper threshold). With the X & Y cursors tracking the rise time measurement, you can then measure the slew rate in A/s by selecting the Cursors menu to read the ΔY/ΔX value. However, since this measurement was performed on the *Max Hold* waveform which plots the peak values of I_{TX_COIL}, this slew rate measurement would be relative to peak current level change — not RMS current level change. To convert to RMS slew rate, you could simply multiply this value by 0.707. Alternately, slew rate relative to an RMS current level change can be measured directly using a second waveform math function that automatically scales the *MAX HOLD* math function to represent RMS current levels. To directly measure slew rate relative to an RMS current level change, continue with the following steps.

27. Turn on the Math2 waveform math function based on the following parameters:
    - Operator = Ax + B
    - Source = Math1 (Max Hold)
    - A = 0.707
    - B = 0
28. Set Math2 vertical scaling = I_{TX_COIL} channel vertical scaling
29. Select the *Rise Time* measurement on Source = Math2(Ax+B).
30. Change Math2 measurement threshold levels to Lower = 45%, Upper = 55%.
31. Select the *Cursors* menu.
32. Record ΔY/ΔX.

Maximum slew rate specifications vary depending upon the selected PTU resonator, but typically range between 100 mArms/ms to 160 mArms/ms. However, there is an exception for transitions at the beginning of short beacons stating that the steady-state RMS current levels must be obtained within 10 ms, which means that the maximum slew rate specification can be exceeded for short beacons. In this example of measuring short beacon slew rate we measured 231 A/s, which is the same as 231 mArms/ms.

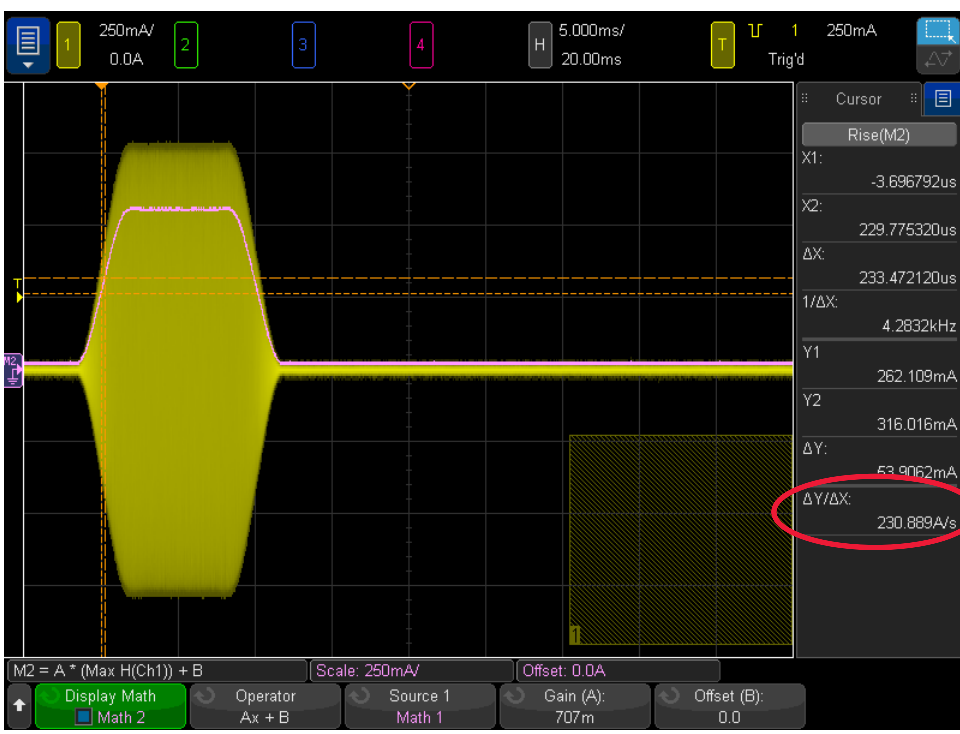

Figure 7. Measuring the slew rate of current level change in terms of Arms/s.

Short Beacon RMS – Cycle Current ($I_{TX\_SHORT\_BEACON}$) and Frequency

To measure *RMS - Cycle* current and *Frequency* of I_{TX_COIL} during short beacons, continue with the following steps:

33. Turn off Math waveforms.
34. Clear all measurements.
35. Set delay (horizontal position) to a value greater than the short beacon transition settling time but less than the short beacon width.
36. Set timebase to 500 ns/div.
37. Select the *AC RMS – N Cycles* measurement on Source = I_{TX_COIL} channel (typically channel-1).
38. Select the *Frequency* measurement on Source = I_{TX_COIL} channel.
39. Turn on measurement statistics.
40. Reset stats.

Figure 8 shows the *AC RMS - Cycle* current and *Frequency* measurements of I_{TX_COIL} during short beacons. To insure that this RMS current measurement was performed during the steady-state portion of the short beacon, the delay/horizontal position was set to 8 ms. With measurement statistics turned on, frequency can be measured with 100 Hz resolution and RMS current can be measured with 10 µA resolution.

Note that waveform averaging (Acquire menu) should not be used. Since these measurements were performed 8 ms after the trigger point (beginning of short beacons), waveform averaging could induce errors due to possible phase jitter of the PTU's resonating frequency relative to the scope's timebase. But since this RMS current measurement was performed at 500 ns/div, each measurement is actually based on the average of 33 cycles of AC current. In addition, measurement statistics provides an additional level of measurement averaging to provide very high resolution measurements.

Also note that you cannot use the *Frequency Counter* to measure frequency on burst type signals such as beacons. You must use the standard *Frequency* parametric measurement, which actually takes the reciprocal of a *Period* measurement on one cycle. The *Frequency Counter*, which can provide significantly higher accuracy and resolution, can only be used when measuring frequency during the power transfer state when I_{TX_COIL} is continuous. Refer to Part 1 of the application note series for additional information on this topic.

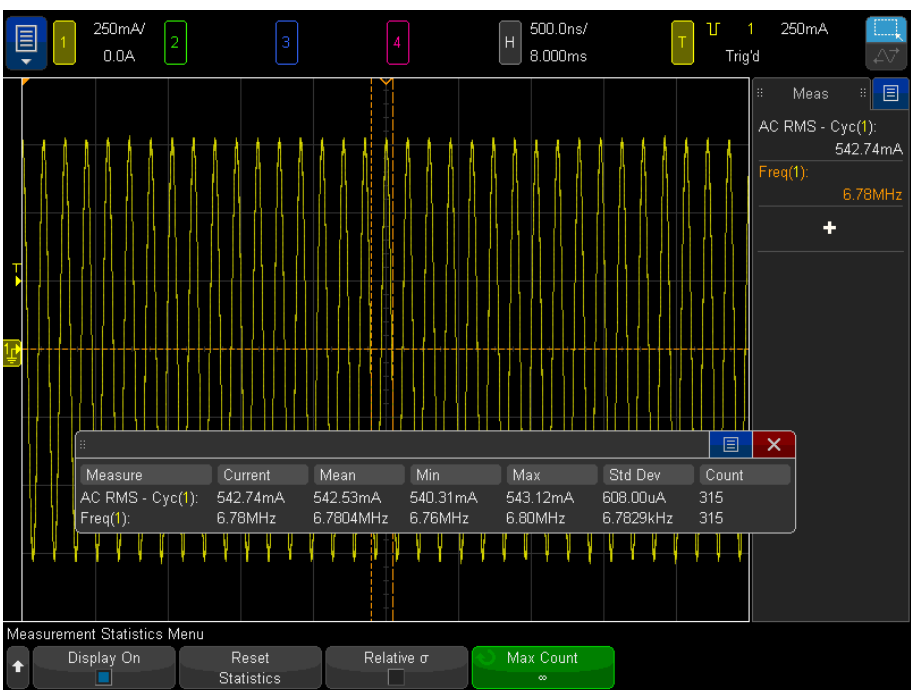

Figure 8. Measuring AC RMS – Cycle current and Frequency of I_{TX_COIL} during short beacons.

Long-beacon-on Period (t_{LONG_BEACON})

Most of the long beacon timing and current measurements can be performed using the same pulse-width trigger setting (low for > 100 ms) that was used for short beacon measurements, which triggers at the beginning of any short beacon. However, in order to qualify on just short beacons that are concatenated with long beacons – as opposed to short beacons that were isolated from long beacons – we must change the *Zone Trigger* condition from "Must Not Intersect" to "Must Intersect". The only long beacon timing measurement that requires a different pulse-width trigger condition is long beacon period ($t_{LONG\_BEACON\_PERIOD}$), which we will save for last. To measure long-beacon-on period (t_{LONG_BEACON}), continue with the following steps:

41. Clear all measurements.
42. Set timebase to 20 ms/div.
43. Set horizontal delay/position to 80 ms.
44. Change *Zone Trigger* Zone #1 from "Must Not Intersect" to "Must Intersect".
45. Turn on the Math1 waveform math function based on the following criteria:
    - Operator = Max Hold
    - Source = I_{TX_COIL} channel (typically channel-1)
    - Set Math1 vertical scaling equal to the I_{TX_COIL} channel's vertical scaling.
46. Select the +Width measurement on Source = Math1 waveform.

Using *Zone Trigger* set to "must intersect", your scope should now be synchronized on just long beacons concatenated with short beacons as shown in Figure 9. The *+Width* measurements on the *Max Hold* waveform measures the width of the combination of the t_{SHORT_BEACON} and t_{LONG_BEACON}. To determine t_{LONG_BEACON}, simply subtract the previously measured t_{SHORT_BEACON} measurement (Figure 5) from this *+Width* measurement (114.3 ms – 10.0 ms = 104.3 ms). The long-beacon-on period (t_{LONG_BEACON}) specification is 105 ms ± 5 ms, which this measurement clearly meets.

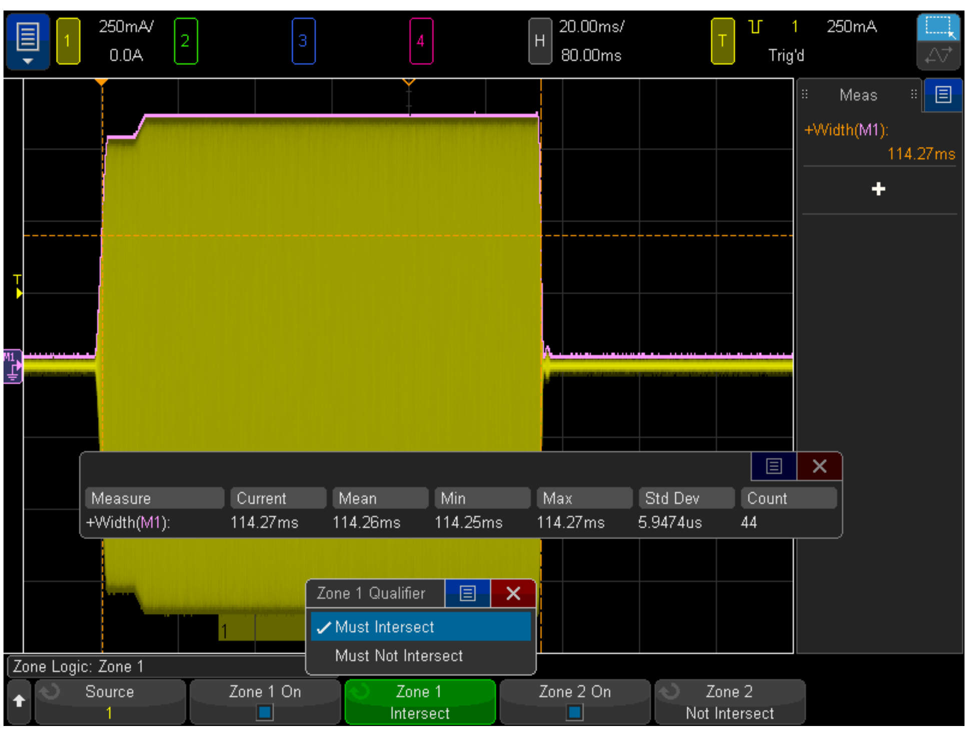

Figure 9. Measuring t_{LONG_BEACON} + t_{SHORT_BEACON}.

Long Beacon Transition Settling Time of I_{TX_COIL}

Measuring the transition settling time when the current level transitions from the end of a short beacon to the beginning of a long beacon can be performed only if there is an appreciable difference in current. If the change in current is less than 5%, then performing this measurement may not be possible. Assuming that there is a significant enough change in current, proceed with the following steps to measure the long beacon *Transition Settling Time*:

47. Turn on the *Zoom* timebase mode (press front-panel magnifying glass button)
48. Adjust zoom timebase (s/div) and delay/horizontal position based on the following conditions:
    - Set zoom timebase to begin after the short beacon settles to its steady-state level.
    - Set zoom timebase to end after the long beacon settles to its steady-state level.
49. Turn on Math2 waveform math function based on the following criteria:
    - Operator = Smoothing
    - Source = Math1 (Max Hold)
    - Smoothing Points = 501
50. Expand scaling of Math2 waveform (use knobs in front-panel Math section)
51. Select *Rise Time* measurement on Source = Math2
52. Change Math2 lower measurement threshold level to 1% and upper threshold level to 90%.

Figure 10 shows the *Transition Settling Time* (Rise Time) when transitioning from a short beacon to a long beacon that has a higher current level. Since this was a relatively small step change in current, performing the rise time measurement on the *Max Hold* waveform (positive peaks of current) would not have provided sufficient resolution. To improve waveform and measurement resolution, we applied a 501-point smoothing filter (Math2) on the *Max Hold* waveform (Math1), and then vertically expanded and centered the Math2 waveform so that we could perform the 1% to 90% rise time measurement on the smoothed waveform.

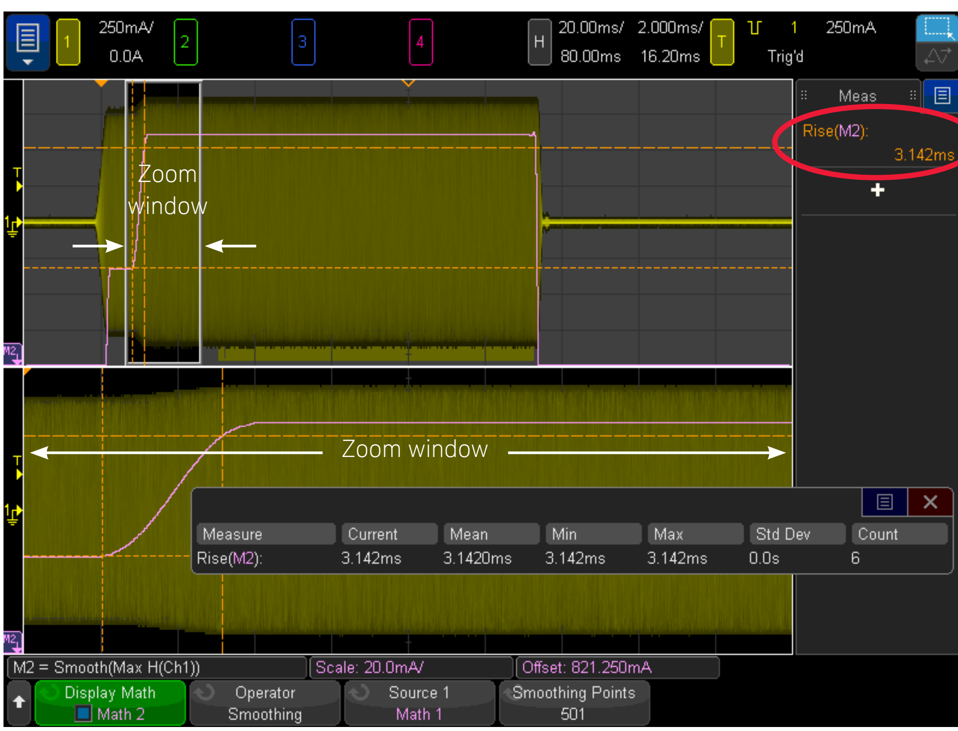

Figure 10. Measuring the Transition Settling Time between short and long beacons.

Long Beacon Slew Rate of I_{TX_COIL}

A long beacon slew rate measurement uses a similar measurement technique that was previously described for short beacon slew rate. However, measuring the slew rate of long beacons requires that there be an appreciable step increase in current level between short beacon current and long beacon current. Assuming that your PTU exhibits at least a 5% step increase in current, continue with the following instructions to measure long beacon slew rate:

53. Turn on the Math3 waveform math function based on the following criteria:
    - Operator = Ax + B
    - Source = Math2
    - A = 0.707, B = 0

    Select a Rise Time measurement on Source = Math3
54. Change Math3 lower measurement threshold level to 45%.
55. Change Math3 upper measurement threshold level to 55%.
56. Select the *Cursors* menu.
57. Record ΔY/ΔX.

Figure 11 shows the results of the long beacon slew rate measurement. To summarize, the Math1 (Max Hold) waveform plotted the positive peaks of I_{TX_COIL}. Math2 (Smoothing) plotted a filtered version of the positive peaks of I_{TX_COIL}. Math3 (Ax + B) scaled the filtered positive peaks of I_{TX_COIL} so that it would represent approximate RMS values of I_{TX_COIL}. The zoom timebase established a measurement window in the region where the short beacon transitioned into a long beacon. The *Rise Time* measurement on the RMS waveform (Math3) based on 45% to 55% threshold levels positions the X & Y cursors where the maximum slew rate occurs so that we could then read and record the value of ΔY/ΔX as slew rate.

Figure 11. Measuring long beacon slew rate.

Long Beacon RMS Current ($I_{TX\_LONG\_BEACON}$) and Frequency

At this point we are now ready to zoom-in to perform a long beacon *RMS – Cycle Current* and *Frequency* measurement.

59. Turn OFF all waveform math functions
60. Clear all measurements.
61. Turn OFF Zoom timebase.
62. Set delay/horizontal position to ~+50 ms.
63. Set timebase to 500 ns/div.
64. Select the *AC RMS – N Cycles* measurement on Source = I_{TX_COIL} channel.
65. Select the *Frequency* measurement on Source = I_{TX_COIL} channel.

Figure 12 shows the results of an AC RMS measurement during long beacons. At this timebase setting and with the extremely low repetition rate of long beacons (as slow as 0.33 Hz), the waveform trace intensity will be very dim. You can increase the trace intensity by pressing the front panel *Intensity* button (under the general-purpose entry knob in the dark gray shaded area), and then rotate that knob.

The scope will not be triggering on the waveforms you see on the scope's display. The scope will be triggering at the beginning of a short beacon that preceded this long beacon, and then delayed acquisition by 50 ms. This means that waveform averaging can't be used due to possible phase jitter (PTU's resonating frequency relative to the scope's more stable timebase). However, each RMS current measurement is actually an average of approximately 30 cycles at this timebase setting. If additional resolution is required, then turn on measurement statistics. But note that accumulating valid measurement statistics will take a long time. In this particular measurement example, long beacons are occurring at a 3 second interval. If you want an average of 10 measurements, then it will take 30 seconds. The scope is triggering as quickly as the long beacons are occurring, which is really slow.

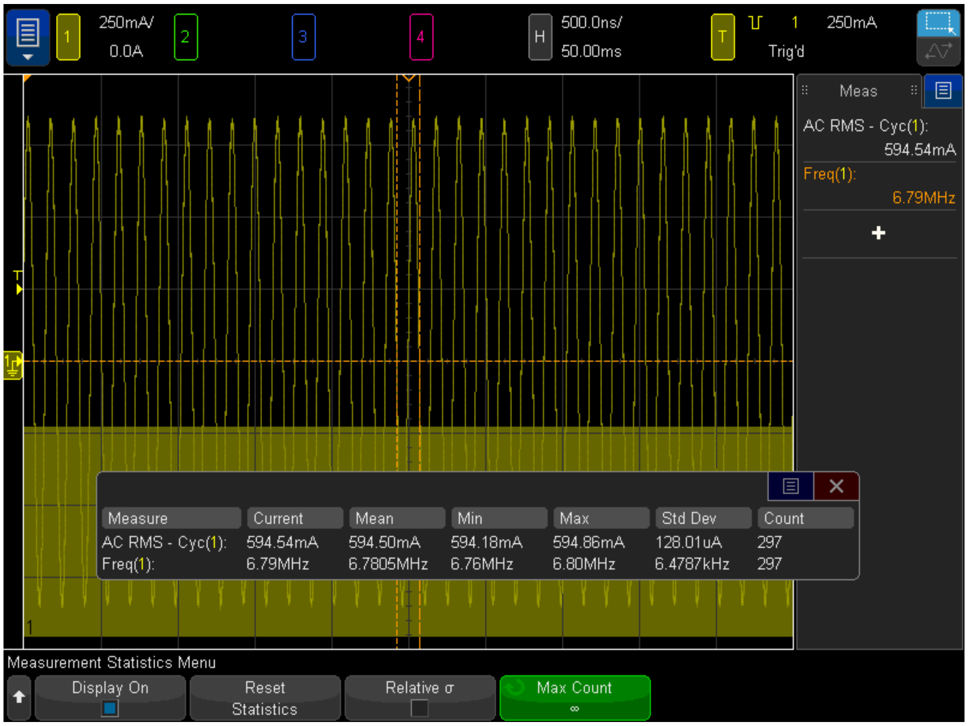

Figure 12. Measuring RMS current and Frequency during long beacons.

Long Beacon Period ($t_{LONG\_BEACON\_PERIOD}$)

Measuring the long beacon period ($t_{LONG\_BEACON\_PERIOD}$) requires that the scope trigger on the first short beacon that follows a long beacon. This can be achieved by changing the pulse-width trigger condition and turning off *Zone Trigger*. To measure the long beacon period ($t_{LONG\_BEACON\_PERIOD}$), continue with the following steps:

66. Turn OFF all waveform math functions.
67. Clear all measurements.
68. Turn off Zone Trigger.
69. Set timebase to 500 ms/div.
70. Set delay/ horizontal position to 1.5 seconds.
71. Select *Pulse Width* triggering based on the following criteria:
    - Source = I_{TX_COIL} channel (typically channel-1)
    - Pulse polarity = Negative
    - Time qualification: > 100 ms, < 160 ms
72. Turn on the Math1 waveform math function based on the following criteria:
    - Operator = Max Hold
    - Source = I_{TX_COIL} channel

Figure 13 shows the scope triggering on the first short beacon after a long beacon. The Math1 (Max Hold) waveform math function plots the positive peaks of I_{TX_COIL}. We now need to measure from one long beacon to the next. To do this we will create another math waveform (Measurement Trend) that will plot the widths of Max Hold waveform. Continue with the following steps:

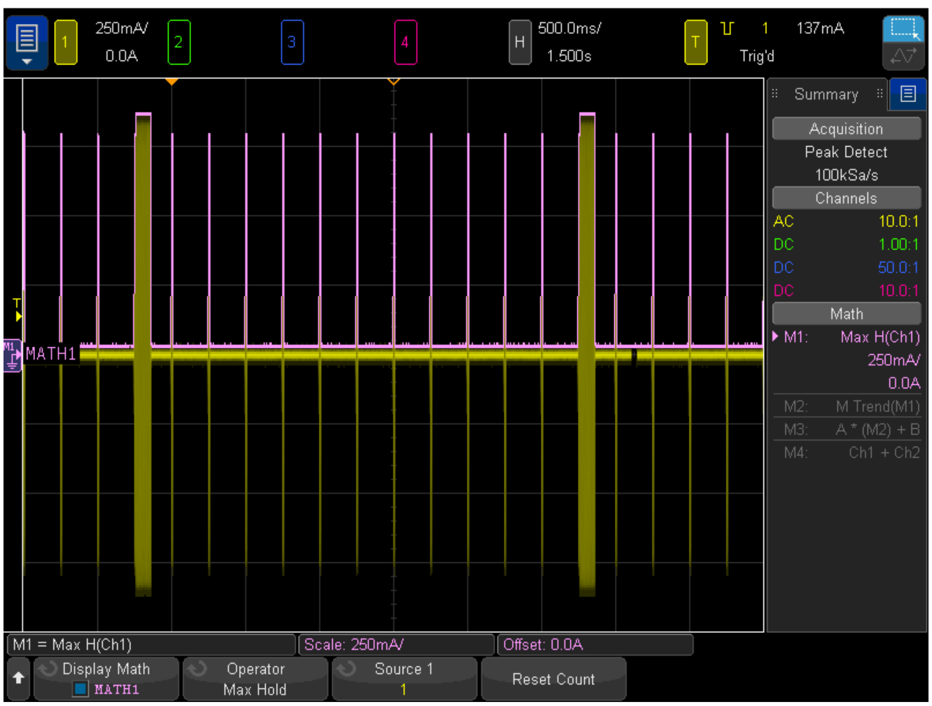

Figure 13. Triggering on the first short beacon after a long beacon using pulse-width trigger based on a time range.

73. Turn on the Math2 waveform math function based on the following critiera:
    - Operator = Measurement Trend
    - Source 1 = Math1 (Max Hold)
    - Measurement = +Width
74. Select a *Period* measurement on the Math2 waveform.

Figure 14 shows the long beacon period ($t_{LONG\_BEACON\_PERIOD}$) measurement. This is a fairly complex measurement. The *Max Hold* math function is running in the background and plotting the positive peaks I_{TX_COIL}, which should look like pulses the width of each beacon burst (long and short). The Math2 function, which is based on a series of +*Width* measurements (Measurement Trend math function) on the Math1 waveform (Max Hold) across screen, plots the width of each beacon on the vertical axis versus time on the horizontal axis (measured time vs oscilloscope time). With the scope's timebase set at 500 ms/div (5 seconds across screen), you should observe two or more large Math2 pulses. These large pulses occur each time a long beacon occurs. The height of these pulses is proportional to the width of each concatenated short + long beacon. The Period measurement on this waveform (Math2) measures the period of long beacons, which is $t_{LONG\_BEACON\_PERIOD}$. Long beacon current should be between 850 ms and 3000 ms.

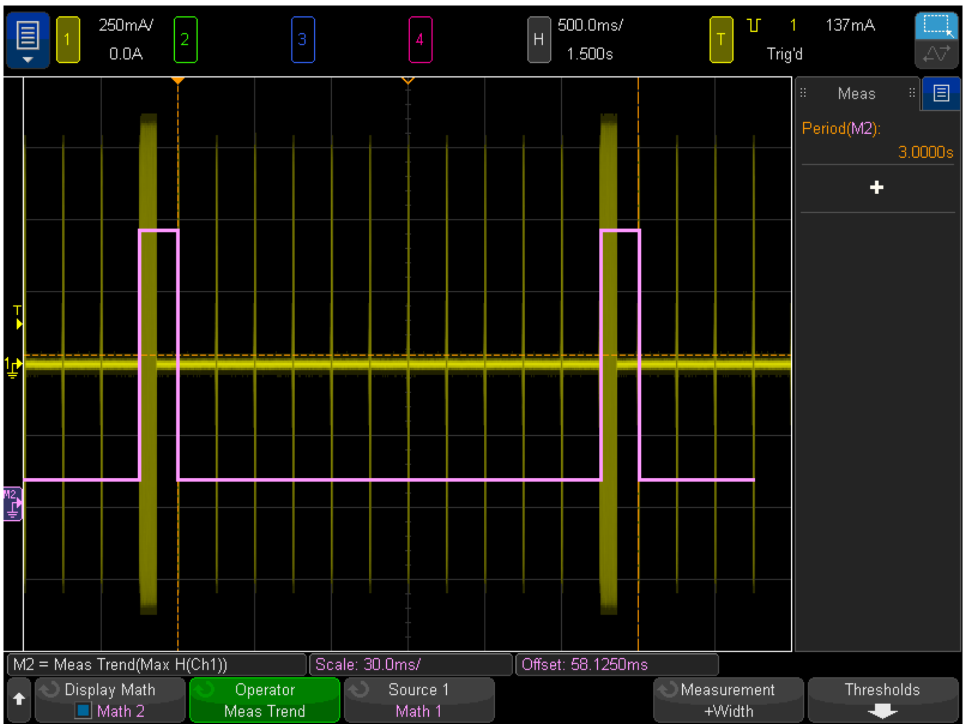

Figure 14. Measuring the long beacon period ($t_{LONG\_BEACON\_PERIOD}$).

Appendix A: Selecting the Right Current Probe

Measuring the various current and timing parameters of PTU or PRU resonator current (I_{TX_COIL} and I_{RX_COIL}) requires a clamp-on Hall-effect AC/DC current probe. This type of current probe can also be used to measure DC I_{RECT} and I_{OUT} charging currents as well. If you are using a Keysight oscilloscope, then the 50-MHz 1147B or the 100-MHz N2893A current probe are recommended. Selecting the right current probe for your A4WP measurements requires careful evaluation of the probe's specifications. The table below summarizes some of the key specifications of these two probes.

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

1. Maximum 15 A peak (AC + DC) continuous if using two current probes connected to the InfiniiVision X-Series oscilloscope.

The "banner" specifications (bandwidth and maximum current) of these two probes clearly meet A4WP requirements of measuring a 6.78 MHz sine wave at up to 5 A-RMS. But these two specifications (bandwidth and maximum current) are mutually exclusive. This is true for other vendor's current probes in this class as well. Current probes have de-rated specifications as a function of input frequency. The two de-rated specifications that you need to closely evaluate are insertion impedance and maximum current at the intended measurement frequency. These specifications are only found in the user's guide and shown as charts. Figure 15 shows that the maximum de-rated current of the N2893A is approximately 5 A-RMS at 6.78 MHz. The 50-MHz bandwidth 1147B current probe, which is a lower-cost current probe, is de-rated to approximately 3.5 A-RMS at 6.78 MHz. So this probe does not meet the A4WP 5 A-RMS requirement. But if your wireless charging system always runs at current levels below 3.5 A-RMS, then this may be a good choice for you. In addition, if you need to measure output DC currents, then the performance of the 1147B should be more than adequate.

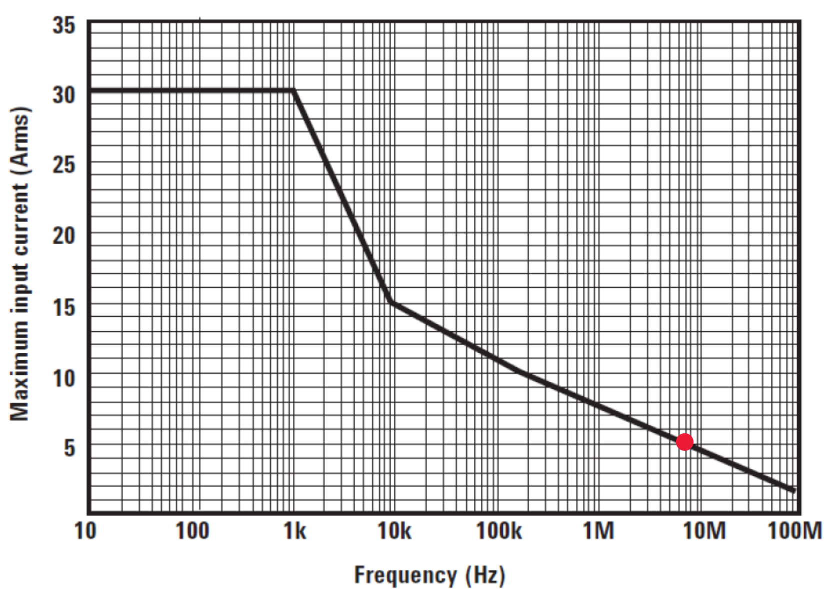

Figure 15. N2893A current probe maximum de-rated current as a function of frequency.

The other important specification to consider is insertion impedance. Figure 16 shows the insertion impedance of the 100-MHz bandwidth N2893A current probe. At ~6.78 MHz, this current probe has a specified insertion impedance of ~40-mΩ, which is the best in the industry. The 50-MHz 1147B has a specified insertion impedance of ~600-mΩ at this same frequency.

Insertion impedance is the effective series loading of the current probe. All oscilloscope probes — current probes and voltage probes — will load the device under test to some degree. Another way to think of it is, they are thieves. They will steal a little bit of what is there. Voltage probes, which typically have very high impedance in parallel with the DUT, steal a little bit of current. Hall-effect current probes steal a little bit of the magnetic field, which it converts into voltage. You need to evaluate how much the added effective series impedance of the current probe will affect the operation and performance of your designs to determine which one will do the job for you. The N2893A is clearly the best probe to use to measure I_{TX_COIL} and I_{RX_COIL} in terms of maximum current and minimum insertion impedance at 6.78 MHz. But as mentioned early, the 1147B might be a good choice for lower category/class DUTs, as well as for measuring output DC currents where loading and bandwidth is not an issue.

The 1147B and N2893A both have the Keysight AutoProbe interface where it plugs into the scope's input BNC. The AutoProbe interface automatically detects that the probe is a current probe (not a voltage probe), and applies the appropriate conversion factors so that all settings (such as vertical scaling) and measurements (such as RMS) are in terms of Amperes, not Volts. A current probe is basically a transducer that actually delivers voltage to the scope that is representative of the measured current. The conversion factor for the 1147B and N2893A is 0.1 V/A. So if the probe detects a magnetic field produced by a 1 Amp current, it converts this level of current to 0.1 Volts. The scope then mathematically converts this voltage back into Amps using the conversion factor of the probe for quantitative measurement purposes.

The AutoProbe interface of the 1147B and N2893A also supplies power to the current probe. AC/DC current probes are "active" probes. This means that they have active electronic circuitry, such as amplifiers, that require power. Some AC/DC current probes require an external power supply or battery to operate.

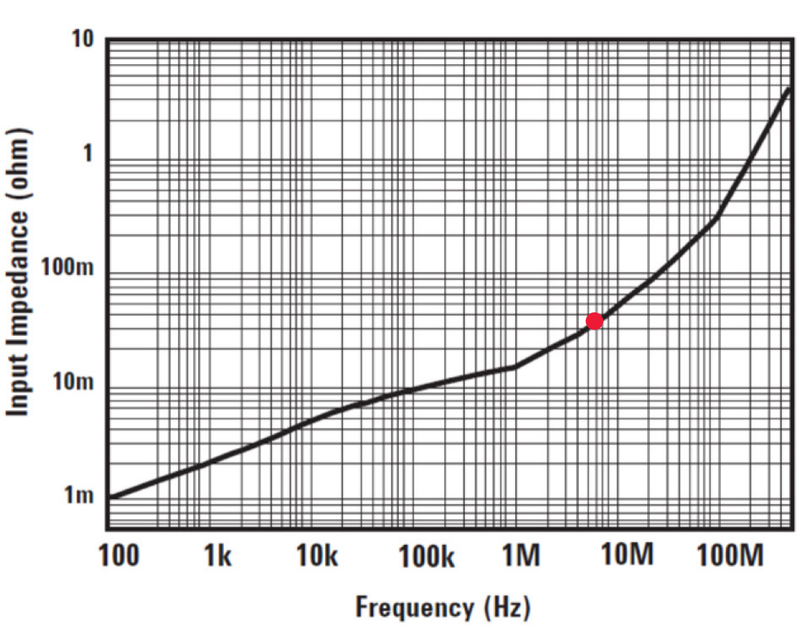

Figure 16. N2893A current probe insertion impedance versus frequency.

Calibrating your Current Probe

Current probes require DC offset calibration and must occasionally be degaussed (demagnetized). Although Hall-effect current probes detect magnetic fields to convert into voltage, they can also build up a magnetic charge. This magnetic charge (core saturation) will induce a DC offset error.

If using the 100-MHz N2893A current probe, you can automatically calibrate DC offset along with demagnetization in the input channel's probe menu. You must disconnect the probe from any DUT, clamp the probe shut as shown in Figure 17 (push the spring lever fully forward to lock), and then just press the **OK** softkey in the probe calibration menu. The probe will first degauss itself, and then perform the offset calibration. This calibration takes about 30 seconds to complete. Note that there is also a **DEMAG** button on the probe that you should use occasionally. When you press this button, the probe demagnetizes itself (if disconnected from the DUT), but it doesn't perform an offset calibration.

If using the 50-MHz bandwidth 1147B, you can manually demagnetize the probe by first disconnecting the probe from the DUT, locked the clamp shut, and then press the **DEMAG** button on the probe. You can then manually calibrate the DC offset error contributed by the probe by rotating a thumbwheel on the probe until the waveform trace for that channel aligns with the ground indicator on the scope's display.

When making measurements on AC signals that are centered on ground, such as I_{TX_COIL} and I_{RX_COIL}, you should use AC coupling in the scope's channel menu. This will further eliminate any DC offset error contributed by the probe. So if the probe begins to build up a magnetic field that induces DC offset error in the probe, which means that it should be degaussed, AC coupling will strip out that DC error component.

Note that the scope itself can also have a DC offset/balance error. A scope's offset/balance error is typically specified around ±0.1 divisions, which can result in less-than-accurate measurements. So when performing RMS measurement on I_{TX_COIL} or I_{RX_COIL}, select the *AC RMS – N Cycles* measurement. This measurement will remove any DC error component contributed by the scope. If the scope that you are using only has the "RMS - Cycle" measurement, then use it. But remember that the measurement will include possible DC offset/balance errors contributed by the scope.

Figure 17. Calibrating (offset correction and degauss) the current probe.

Related Literature

Publication title	Publication number
InfiniiVision Oscilloscope Probes and Accessories - Selection Guide Data Sheet	5968-8153EN
InfiniiVision 4000 X-Series Oscilloscopes - Data Sheet	5991-1103EN
Triggering on Infrequent Anomalies and Complex Signals using Zone Trigger - Application Note	5991-1107EN
InfiniiVision 6000 X-Series Oscilloscopes - Data Sheet	5991-4087EN
InfiniiVision 3000T X-Series Oscilloscopes - Data Sheet	5992-0140EN
Characterizing Passive Components in Wireless Power Transfer (WPT) Systems - Application Note	5992-0771EN
Alliance for Wireless Power (A4WP) Measurements Using an Oscilloscope (Part 1): I_{TX_COIL} Measurements during the Power Transfer State (non-beacons) - Application Note	5992-1109EN
Alliance for Wireless Power (A4WP) Measurements Using an Oscilloscope (Part 3): Power and Efficiency Measurements - Application Note	5992-1111EN

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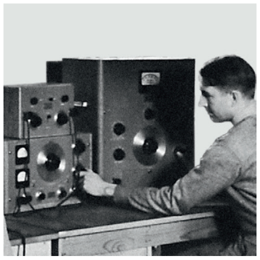
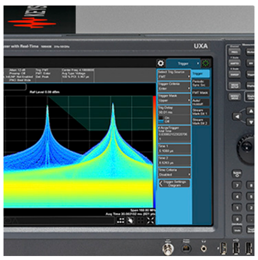


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