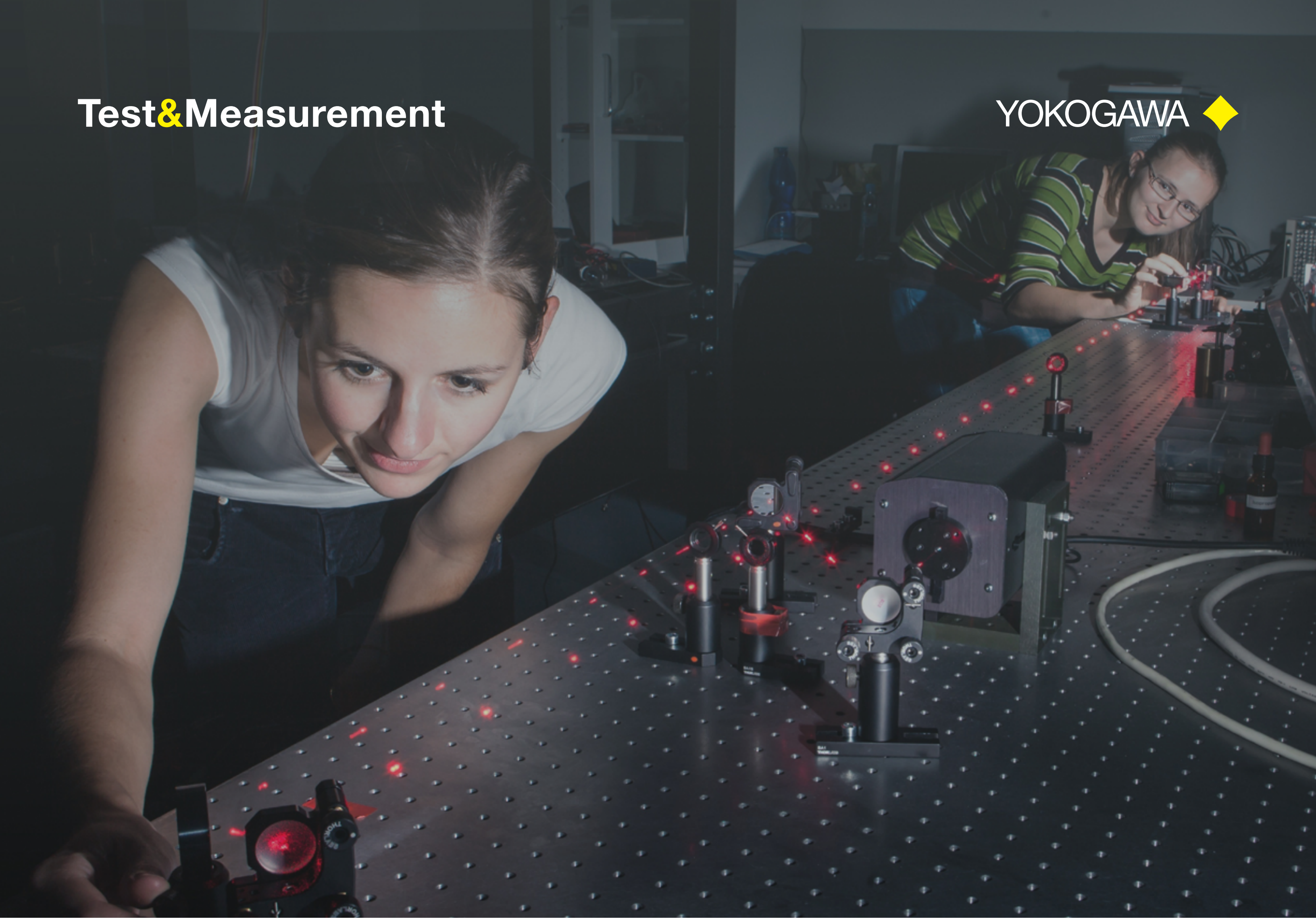
Test&Measurement

YOKOGAWA



Optical Spectrum Analyzer Setting Guidelines for Pulsed Light Measurement

Overview of Pulsed Light Measurement

Why use pulsed light?

A semiconductor laser emits light by a driving current. This drive current causes the semiconductor laser chip to generate heat, causing a shift in the output wavelength and potentially damaging the laser. To avoid such problems, pulse-driven light emission is widely used. Furthermore, high-power industrial lasers may require an energy accumulation period before the power is released as a short pulse. The pulse drive conditions of these lasers are designed with repetition frequencies and duty ratios that depend on the application. To accurately measure pulsed light using an optical spectrum analyzer (OSA), it is necessary to understand the characteristics of the OSA and select the appropriate measurement method and settings.

Precision Making

Common challenges of pulsed light measurement

An OSA samples and measures the total power of a specific wavelength segment while sweeping the wavelength and displays it as an optical spectrum. Normally, it is assumed that the optical input signal is constant during the OSA wavelength sweep. In other words, a signal that turns the optical input signal on or off, such as pulsed light, is not expected. Therefore, if the OSA measurement method and condition settings are not suitable for the pulsed light drive conditions, the measured spectrum may appear segmented or choppy, as shown in Figure 1.

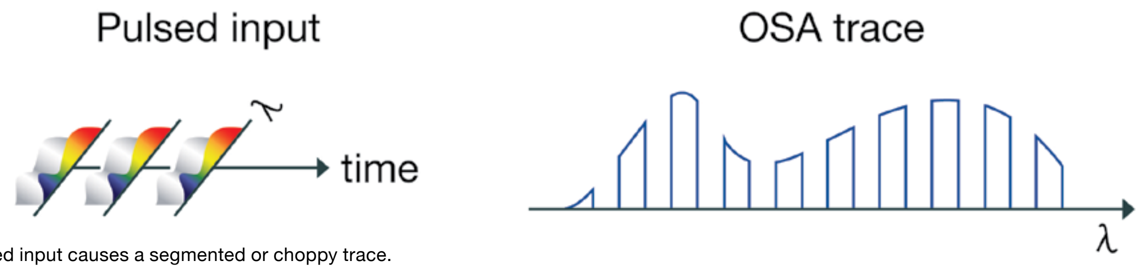


Figure 1. A pulsed input causes a segmented or choppy trace.

Pulsed light measurement by a Yokogawa Test&Measurement OSA

Depending on the driving conditions of the pulsed light, Yokogawa Test&Measurement OSAs offer three types of measurement methods: time average spectrum measurement, external trigger synchronous measurement, and peak hold measurement.

1. **Time average spectrum measurement:** The average power of the pulsed light is measured as the power of the light spectrum. It can be used even when the pulse width is narrow.
2. **External trigger synchronous measurement:** By supplying the pulsed signal from the light source as an external electrical trigger signal synchronized with the optical pulse to the OSA, the peak value of the optical pulse is captured. The measurable pulse width is 50 µs or more.
3. **Peak hold measurement:** Captures the peak value within the repeating cycle of the optical pulse. The measurable pulse width is 100 µs or more.

● : Available
○ : Available (conditional*)

Measurement modes	AQ6360	AQ6370 AQ6373 AQ6374	AQ6375 AQ6376 AQ6377
Time average spectrum	●	●	●
External Trigger		●	○
Peak Hold		●	○

Figure 2: Applicable measurement modes per OSA model. *The external trigger and peak hold measurements are not available in HIGH1, HIGH2, and HIGH3 of the AQ6375, AQ6376, and AQ6377, where the high dynamic range “CHOP” mode is used.

Pulsed light measurement in time average mode (normal mode)

In time average mode, the time average power of pulsed light is measured as the optical spectral power of each wavelength. When the pulsed light is a square wave, the measured average light power is calculated as:

(Peak Power of Light Pulse [mW]) × (Duty Ratio of Pulsed Light)

Therefore, the smaller the duty ratio of pulsed light, the lower the measured power. To measure the average power correctly in this mode, the repetition frequency must be high to some extent. Otherwise, it may need to be measured in a high-sensitivity setting or by increasing the number of averages.

Features of time average mode

- No external trigger signal is required.
- Cannot handle irregular pulse signals because the average power fluctuates.
- It can handle any signal such as short pulse and long repetition period.
- High power pulsed light with peak power exceeding 1W can be measured. However, there are limits on maximum pulse peak power and maximum safe average power.
- The measured optical power is low because the average power of the optical pulse is measured. There are likely to be cases where measurement is not possible due to insufficient power. To ensure a high dynamic range, use a high sensitivity setting to slow down the measurement. If the average power is high, it could measure faster than other methods.
- There are restrictions on sensitivity settings depending on the repetition frequency. When the repetition frequency is low, increase the measurement sensitivity to slow down the measurement.
- High dynamic range mode (CHOP), double speed mode, and averaging function can be applied.

Constraints on sensitivity setting by repetition frequency

The pulse repetition frequency is roughly divided into the following three groups, and the measurement method can be considered accordingly.

- **Pulse repetition frequency (MHz):** At very high pulse repetition frequencies, the reaction speed of the detection circuit in the OSA is slow enough so that, even at the lowest sensitivity setting (NORM HOLD), the OSA can measure it as a continuous wave, regardless of the device setting. Set the sensitivity according to the average power.
- **Pulse repetition frequency (kHz):** For kHz class pulse repetition frequencies, On/Off distortion due to pulsed light may be noticeable. Eliminate this effect by selecting a high sensitivity setting and slowing down the reaction speed of the detection circuit. It is necessary to set the sensitivity considering both the average power and the repetition frequency.
- **Pulse repetition frequency (Hz):** If the pulse repetition frequency is very low, set the sensitivity considering the repetition frequency. If the highest sensitivity setting does not eliminate the distortion of the recorded spectrum, add an averaging process. Assuming that the number of averaging is n, the minimum repetition frequency of each sensitivity setting is multiplied by 1/n. Adding the number of averaging significantly reduces the measurement speed. Use it only when the maximum sensitivity setting is insufficient.

The table in Figure 3 shows the estimated minimum repeat frequency that can be measured with each sensitivity setting.

	Minimum repetition frequency		
Sensitivity setting	AQ6360	AQ6370 AQ6373 AQ6374	AQ6375 AQ6376 AQ6377
NORM/HOLD	1 MHz	200 kHz	200 kHz
NORM/AUTO	1 MHz	100 kHz	100 kHz
NORMAL	200 kHz	33 kHz	33 kHz
MID	50 kHz	10 kHz	10 kHz
HIGH1	10 kHz	3.3 kHz	1 MHz
HIGH2	2 kHz	660 Hz	1 MHz
HIGH3	N/A	160 Hz	1 MHz

Figure 3. Estimated minimum repetition frequency. HIGH1-3 of AQ6375/76/77 is in high dynamic range mode (CHOP) and the averaging does not reduce the minimum repeat frequency in this mode.

Optical input power conditions

The time average mode can measure high-power pulsed light with a peak power of more than 1W. However, pulsed light of which average spectral power exceeds the OSA maximum input power specification cannot be measured.

[CAUTION] There is a limit to the optical power that can be input to the OSA. See “Guidelines for Pulsed Light Input Power” in this app note for more information.

Maximum input power	AQ6360	AQ6370	AQ6373		AQ6374		AQ6375	AQ6376	AQ6377
			400 – 550 nm	550 – 1100 nm	400 – 550 nm	550 – 1750 nm			
dBm	+20	+20	+10	+20	+10	+20	+20	+13	+13
W	0.1	0.1	0.01	0.1	0.01	0.1	0.1	0.02	0.02

Figure 4. Maximum input power is the maximum spectral power per measurement resolution.

Pulsed light measurement in external trigger mode

The external trigger mode uses an external electrical trigger signal to control the timing of OSA measurements. Data measurement, or signal sweeping, starts when triggered by an external electrical trigger to the input terminal on the rear panel of the instrument. Supplying an external trigger signal synchronized with the optical pulse signal to the OSA captures the peak value of the optical pulse. The OSA takes one sample of the detection circuit each time it receives the trigger signal from the laser pulse, then increments it to the next wavelength step to take the next sample when it receives the next trigger pulse signal. Refer to the user’s manual of a model to view their specific electrical properties of trigger signal.

Features of external trigger mode

- Requires an external trigger signal synchronized with the optical pulse.
- It can handle irregular pulse signals.
- The maximum optical pulse peak power is the maximum input power of an OSA (for AQ6370, +20 dBm).
- The minimum optical pulse width is 50 μs (for Norm/Hold sensitivity). As the minimum pulse width depends on the sensitivity setting, the higher sensitivity settings increase the minimum pulse width.
- Since the peak power of the optical pulse is captured, the optical power measured is higher than that of the time average mode. Problems due to insufficient power are unlikely to occur and measurement is fast because a high dynamic range can be secured even with a low sensitivity setting.
- There are no restrictions on sensitivity settings depending on the repetition frequency, which means it is easy to speed up the measurement using the low sensitivity setting.
- High dynamic range mode (CHOP), double speed mode, and averaging function cannot be applied.

Minimum pulse width condition

The external trigger mode requires a pulse width of at least 50 μs to capture the peak of the optical pulse. The minimum pulse width depends on the measurement sensitivity setting used, and the higher the measurement sensitivity, the wider the minimum pulse width at which peaks are captured.

The suitability of this mode is mainly determined by the pulse width to be measured because the gain of the detection circuit and the response speed are inversely proportional. At low sensitivity settings, the detection circuit gain is low and the response is fast, allowing for the correct measurement of short pulse width peaks. At high sensitivity settings, the gain of the detection circuit is high and the response is slow, so short pulse width peaks cannot be measured correctly.

The table in Figure 5 shows the estimated minimum pulse width that can be measured with each sensitivity setting.

Sensitivity setting	Minimum pulse width	
	AQ6370 AQ6373 AQ6374	AQ6375 AQ6376 AQ6377
NORM/HOLD	50 μs	50 μs
NORM/AUTO	300 μs	300 μs
NORMAL	1 ms	1 ms
MID	3 ms	3 ms
HIGH1	10 ms	-
HIGH2	50 ms	-
HIGH3	200 ms	-

Figure 5. Estimated minimum pulse width. HIGH1-3 of AQ6375/76/77 is in high dynamic range mode (CHOP) and the AQ6360 does not have the external trigger mode.

External trigger and timing adjustment

To measure the peak power of the optical pulse, connect an external trigger signal synchronized with the optical pulse to the *TRIGGER IN* port on the back of the OSA, and set *TRIG INPUT MODE* in the OSA system menu to *SMPL TRIG MODE*. The *SMPL TRIGGER MODE* triggers at the rising edge (or falling edge) of the input external trigger signal to measure 1 point. Adjust the timing as needed to capture the peak of the optical pulse correctly. The OSA has a delay of about 70 μs from trigger to measurement. It also has a function to add a delay time in the range of 0 to 1000 μs.

Optical input power conditions

In external trigger mode, OSA captures the peak power of the optical pulse. Optical pulsed light that exceeds the OSA maximum input power specifications cannot be measured. The peak power of a measurable optical pulse is at most +20 dBm (0.1 W). Figure 6

[CAUTION] There is a limit to the optical power that can be input to the OSA. See “Guidelines for Pulsed Light Input Power” in this app note for more information.

Maximum input power	AQ6360	AQ6370	AQ6373		AQ6374		AQ6375	AQ6376	AQ6377
			400 – 550 nm	550 – 1100 nm	400 – 550 nm	550 – 1750 nm			
dBm	+20	+20	+10	+20	+10	+20	+20	+13	+13
W	0.1	0.1	0.01	0.1	0.01	0.1	0.1	0.02	0.02

Figure 6. Maximum input power is the maximum spectral power per measurement resolution.

Pulsed light measurement in peak hold mode

Peak hold mode is a measurement mode that does not require an external trigger signal. The detection signal is recorded for the specified period for each measurement wavelength, and the maximum value of the data acquired during that period is used as the power for that measurement wavelength. The period during which the detection signal is recorded is called the “hold time” and is set to a value larger than the pulse repetition period (1/repetition frequency).

This allows users to measure at least one pulse within the hold time. The OSA essentially takes one sample from one laser pulse and repeats the movement of the measurement wavelength and the recording of the output signal of the detection circuit.

Features of peak hold mode

- No external trigger signal is required.
- The maximum optical pulse peak power is the maximum input power of the OSA (for AQ6370, +20 dBm).
- The minimum optical pulse width is 100 μs (for Norm/Hold). The minimum pulse width depends on the sensitivity setting. Higher sensitivity settings increase the minimum pulse width.
- Since the peak power of the optical pulse is captured, the optical power measured is higher than that of the time average mode. Problems due to insufficient power are unlikely to occur and measurement is fast because a high dynamic range can be secured even with a low sensitivity setting.
- There are no restrictions on sensitivity settings depending on the repetition frequency. It is easy to speed up the measurement using the low sensitivity setting.
- High dynamic range mode (CHOP), double speed mode, and averaging function cannot be applied.
- Not recommended for measuring irregular pulse signals because it is necessary to set the hold time according to the minimum repetition frequency.

Minimum pulse width condition

The peak hold mode requires a pulse width of at least 100 μs to capture the peak of the optical pulse. In addition, the minimum pulse width depends on the measurement sensitivity setting used; the higher the measurement sensitivity, the wider the minimum pulse width at which peaks are captured. The suitability of this mode is mainly determined by the pulse width to be measured because the gain of the detection circuit and the response speed are inversely proportional.

At low sensitivity settings, the detection circuit gain is low and the response is fast, allowing for the correct measurement of short pulse width peaks. At high sensitivity settings, the gain of the detection circuit is high and the response is slow, resulting in incorrect measurements of short pulse width peaks.

The table in Figure 7 shows the minimum pulse width that can be measured with each sensitivity setting.

	Minimum pulse width	
Sensitivity setting	AQ6370 AQ6373 AQ6374	AQ6375 AQ6376 AQ6377
NORM/HOLD	100 μs	100 μs
NORM/AUTO	300 μs	300 μs
NORMAL	1 ms	1 ms
MID	3 ms	3 ms
HIGH1	10 ms	-
HIGH2	50 ms	-
HIGH3	200 ms	-

Figure 7. Estimated minimum pulse width. HIGH1-3 of AQ6375/76/77 is in high dynamic range mode (CHOP) and the AQ6360 does not have the external trigger mode.

Hold time setting

Set the hold time to a value larger than the pulse repetition period (1/repetition frequency). With an OSA, the hold time can be set

Optical input power conditions

In peak hold mode, since an OSA captures the peak power of the optical pulse, an optical pulsed light that exceeds the OSA maximum input power specifications cannot be measured. This results in the peak power of a measurable optical pulse being at

[CAUTION] There is a limit to the optical power that can be input to the OSA. See "Guidelines for Pulsed Light Input Power" in this app note for more information.

Maximum input power	AQ6360	AQ6370	AQ6373		AQ6374		AQ6375	AQ6376	AQ6377
			400 – 550 nm	550 – 1100 nm	400 – 550 nm	550 – 1750 nm			
dBm	+20	+20	+10	+20	+10	+20	+20	+13	+13
W	0.1	0.1	0.01	0.1	0.01	0.1	0.1	0.02	0.02

Figure 8. Maximum input power is the maximum spectral power per measurement resolution.

Guidelines for pulsed light input power

When measuring pulsed light, it is recommended to use the pulse peak power below the maximum safe input power of the OSA to prevent damage inside the equipment. Since the limitation differs depending on the emission condition of the pulsed light, there are some additional considerations, listed below. It should be noted that these are merely estimated values and do not guarantee safety.

When the pulse width exceeds 1 μs

- The pulse peak power must not exceed the OSA maximum safe input power.

When the pulse width is 1 μs or less

- The pulse peak power must not exceed 316W.

  - Pulse peak power (W) × pulse width (s) ÷ repetition cycle (s), or
  - Pulse peak power (W) × pulse width (s) × repetition frequency (Hz)

Maximum input power	AQ6360	AQ6370	AQ6373		AQ6374		AQ6375	AQ6376	AQ6377
			400 – 550 nm	550 – 1100 nm	400 – 550 nm	550 – 1750 nm			
dBm	+25	+25	+10	+20	+10	+20	+25	+20	+20
W	0.316	0.316	0.01	0.1	0.01	0.1	0.316	0.1	0.1

Figure 9. OSA maximum safe input power. The above guidelines do not include the optical power that can be measured by an OSA.

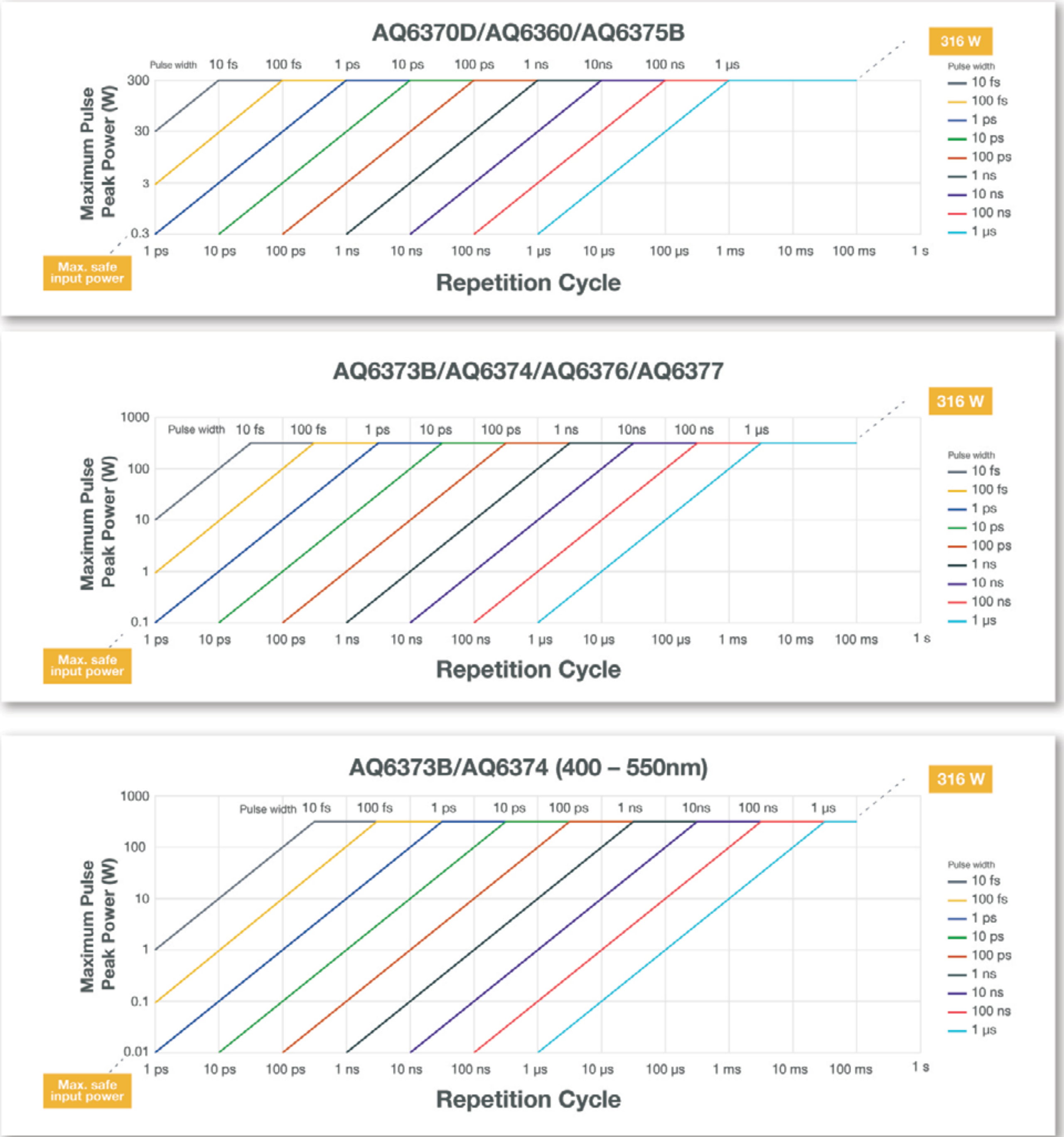


Figure 10. How to obtain the maximum pulse peak power from pulse conditions.

Summary of the Guidelines

For pulsed light measurements, it is best to first ensure compliance with the recommendations in "Guidelines for Pulsed Light Input Power." The time average mode is the easiest and most flexible way to measure pulsed light.

In some instances, though, it may make better sense to consider using the external trigger or peak hold modes. Examples include when irregular pulsed light is present, when measurement is not possible because the average power is below the measurement sensitivity due to the relationship between the peak power and the duty ratio, and when measurement takes too long because the high sensitivity setting is required due to very low repetition frequency.

The suitability of using either the external trigger mode or peak mode is determined by the pulse width and the required sensitivity setting, or by the availability of an external trigger and the minimum pulse width.

	Time averaging mode (normal mode)	External trigger mode	Peak hold mode
External trigger	No	Required	No
Irregular pulse	Not applicable	Applicable	Applicable but not recommended
Minimum pulse width	No restriction	50 µs (NORM/HOLD) Changes depending on sensitivity setting.	100 µs (NORM/HOLD)
Maximum input power	High power pulse light with peak power exceeding 1W can be measured. However, there are restrictions on the maximum pulse peak power and maximum safe average power. Refer to the section "Guidelines for Pulsed Light Input Power" in this app note.	Pulse peak power must be less than or equal to the OSA's maximum input power (for AQ6370, 0.1W or less). Refer to the maximum input power of each product in Figures 6 and 8.	
Measured power	Average power	Pulse peak power	
How to select sensitivity	First, refer to the repetition frequency, then the required dynamic range.	First, refer to the pulse width, then the required dynamic range.	
Selection guidelines	Regular pulse signal with a constant repetition frequency. Average power is above measurement sensitivity.	The pulse width satisfies the condition for each sensitivity. Refer to the guideline for the minimum pulse width for each sensitivity setting in Figures 6 and 8. There is an external trigger signal.	N/A
Tips	Shorten the measurement time by increasing the repetition frequency. When the repetition frequency is extremely low, measurement becomes possible by increasing the number of averages. However, averaging leads to a significant increase in measurement time. It is not recommended to use anything other than the sensitivity setting HIGH3.	If the repetition frequency is less than 20 Hz, it may be faster than the time average mode.	

Figure 11. OSA setting guide for pulsed light measurement.

Examples (AQ6370)

Pulse width 100 µs, pulse peak power 0.1 W, repetition frequency 1 kHz

Any measurement mode can be selected according to the pulse width condition. If there is an external trigger signal, select "external trigger." Otherwise, select "peak hold." For external trigger and peak hold, make sure that the pulse peak is below "maximum input power."

Mode	Pulse width	Pulse peak power		Repetition frequency	Sensitivity setting	Measured power	Noise level	Dynamic range
Time average	100 µs	0.1 W	+20 dBm	1 kHz	HIGH2	+10 dBm	-85 dBm	95 dB
External trigger					**Norm/ Hold**	**+20 dBm**	**-25 dBm**	**45 dB**
Peak hold					**Norm/ Hold**	**+20 dBm**	**-25 dBm**	**45 dB**

Figure 12. Pulse measurement modes for 100 µs pulse width.

Pulse width 50 µs, pulse peak power 0.1 W, repetition frequency 1 kHz

"Time average" or "external trigger" can be selected according to the pulse width condition. Select "external" if there is an external trigger signal, as this is faster. In the case of "external trigger," make sure that the pulse peak is below the maximum input power. In the case of "time average," make sure that the pulse peak is below the maximum safe input power according to the pulse width condition, and set the sensitivity setting to HIGH2 or higher according to the repetition frequency.

Mode	Pulse width	Pulse peak power		Repetition frequency	Sensitivity setting	Measured power	Noise level	Dynamic range
Time average	50 µs	0.1 W	+20 dBm	1 kHz	HIGH2	+7 dBm	-85 dBm	92 dB
External trigger					**Norm/ Hold**	**+20 dBm**	**-25 dBm**	**45 dB**

Figure 13. Pulse measurement modes for 50 µs pulse width.

Pulse width 1 µs, pulse peak power 0.1 W, repetition frequency 1 kHz

Select "time average" according to the pulse width condition. Make sure that the pulse peak is below the maximum safe input power according to the pulse width condition. Set the sensitivity setting to HIGH2 or higher according to the repetition frequency.

Mode	Pulse width	Pulse peak power		Repetition frequency	Sensitivity setting	Measured power	Noise level	Dynamic range
Time average	1 µs	0.1 W	+20 dBm	100 kHz	Norm/Hold	+10 dBm	-55 dBm	45 dB
				10 kHz	MID	0 dBm	-75 dBm	75 dB
				1 kHz	**HIGH2**	**-10 dBm**	**-85 dBm**	**75 dB**
				200 Hz	HIGH3	-17 dBm	-90 dBm	73 dB

Figure 14. Pulse measurement mode for 1 µs pulse width.

Pulse width 1 ns, pulse peak power 10 W, repetition frequency 1 kHz

Select "time average" according to the pulse width condition. Make sure that the pulse peak is 316 W or less and the average power is below the maximum safe input power according to the pulse width condition. Set the sensitivity setting to HIGH2 or higher according to the repetition frequency.

Mode	Pulse width	Pulse peak power		Repetition frequency	Sensitivity setting	Measured power	Noise level	Dynamic range
Time average	1 ns	10 W	+40 dBm	100 kHz	Norm/Hold	0 dBm	-65 dBm	45 dB
				10 kHz	MID	-10 dBm	-75 dBm	65 dB
				1 kHz	**HIGH2**	**-20 dBm**	**-85 dBm**	**65 dB**
				200 Hz	HIGH3	-27 dBm	-90 dBm	63 dB

Figure 15. Pulse measurement mode for 1 ns pulse width.

Appendix

The effect of an OSA's sensitivity setting

The OSA sensitivity setting has a significant effect on the quality and duration of pulsed light measurements. In time average mode, the sensitivity setting limits the measurable pulse repetition frequency, and in external trigger mode and peak hold mode, the minimum pulse width is limited. These are related to the response speed of the OSA detection circuit.

The measurement sensitivity setting determines which OSA detection circuit is selected. Each circuit corresponds to each sensitivity setting and provides a specific gain and response speed. The gain and response speeds are inversely related – increasing the gain slows down the response speed. At high sensitivity settings such as HIGH1, while the gain of the detection circuit increases, both the reaction speed and wavelength sweep become slower. Conversely, with low sensitivity settings such as Norm/Hold and Normal, the gain of the detection circuit is reduced, while the reaction speed and wavelength sweep are faster.

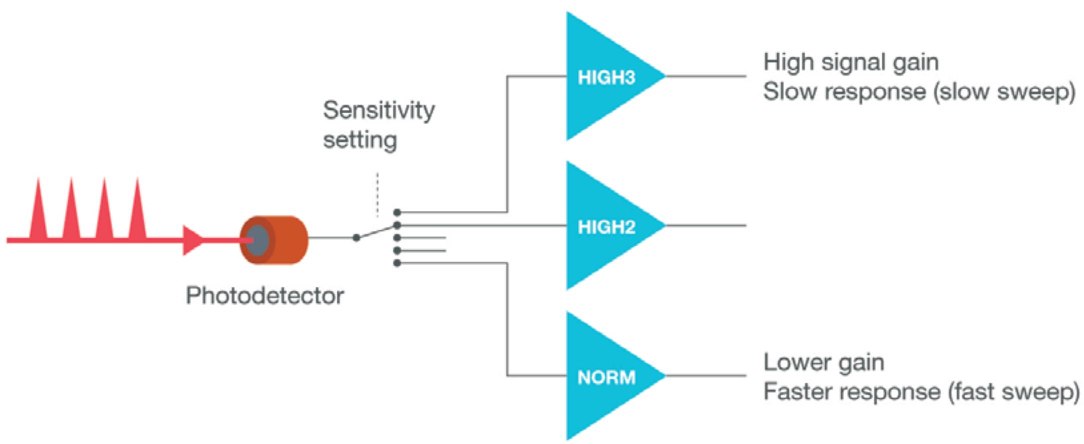


Figure 16. Sensitivity settings influence response time.

In time averaging mode, if the OSA responds too quickly compared to the pulse repetition frequency, there will be a clear on/off distortion in the recorded spectrum. Therefore, it is very important to select the appropriate measurement sensitivity for the pulse repetition frequency.

In external trigger mode and peak hold mode, peaks of short pulse width can be measured correctly at low sensitivity settings where the gain of the detection circuit is low and the response is fast. However, at high sensitivity settings, the gain of the detection circuit is high and the response is slow, resulting in incorrectly measured short pulse width peaks. Therefore, it is very important to select the appropriate measurement sensitivity for the pulse width to be measured.

OSA detection signal

In the low sensitivity setting, P(λ) is high because the response of the detection circuit is fast. The peak of the pulse is captured. At each wavelength, the pulse detector signal is recorded at specific time intervals. The maximum signal acquired at the time interval is used as the power value at a specific wavelength. In the high sensitivity setting, P(λ) is low because the response of the detection circuit is slow. The peak of the pulse cannot be captured.

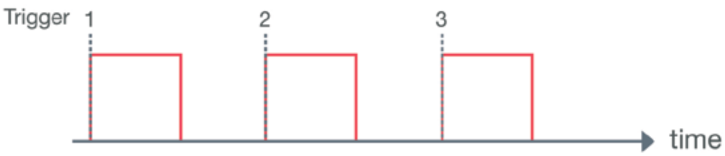


Figure 17. Laser output pulse signal.

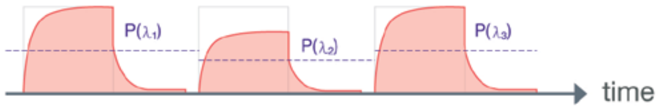


Figure 18. Detection circuit output signal (low sensitivity).

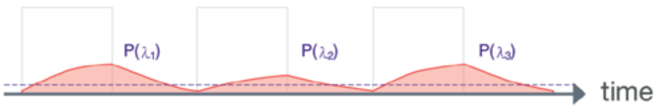


Figure 19. Detection circuit output signal (high sensitivity).

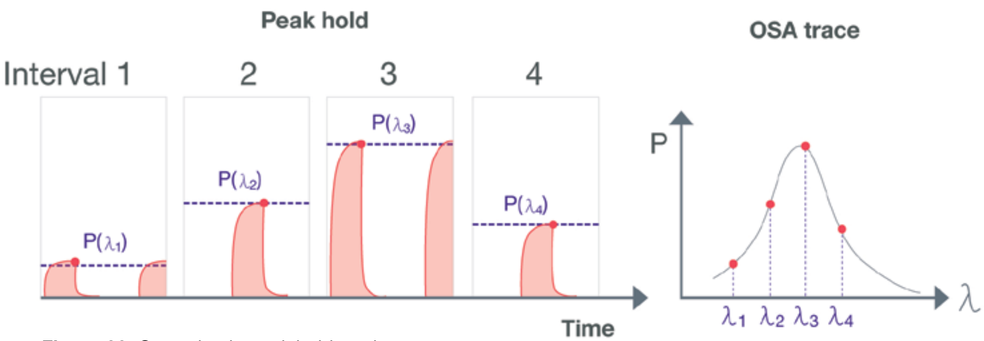


Figure 20. Operation in peak hold mode.

Yokogawa's global network of 114 companies spans 62 countries. Founded in 1915, the company has grown to over $4B USD due to a commitment to cutting-edge research and innovation. Yokogawa is active in the industrial automation and control (IA), test and measurement, aviation, and other businesses segments.

Yokogawa has been developing measurement solutions for over 100 years, consistently finding new ways to give R&D teams the tools they need to gain the best insights from their measurement strategies. The company has pioneered accurate power measurement throughout its history and is the market leader in optical spectrum analyzers.

Yokogawa instruments are renowned for maintaining high levels of precision and for continuing to deliver value for far longer than the typical shelf-life of such equipment.

Yokogawa believes that precise and effective measurement lies at the heart of successful innovation - and has focused its own R&D on providing the tools that researchers and engineers need to address challenges great and small.

Yokogawa takes pride in its reputation for quality, both in the products it delivers - often adding new features in response to specific client requests - and the level of service and advice provided to clients, helping to devise measurement strategies for even the most challenging environments.

Meet the Precision Makers at
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