

## General Description

The AOZ23695RQI is a high-efficiency, easy-to-use DC/DC synchronous buck regulator capable of operation from a 5V to 28V input bus. The device is capable of supplying 18A of continuous output current with an output voltage adjustment from 0V to 1.8V by controlling VID0 and VID1 signals.

A proprietary constant on-time PWM control with input feed-forward results in ultra-fast transient response while maintaining relatively constant switching frequency over the entire input voltage range.

The devices feature multiple protection functions such as  $V_{CC}$  under-voltage lockout, cycle-by-cycle current limit, output over-voltage protection, short-circuit protection, and thermal shutdown.

The AOZ23695RQI is available in a 5mm×5mm QFN-36L package and is rated over a -40°C to +85°C ambient temperature range.

## Features

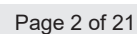
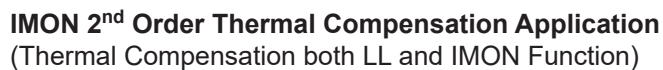
- Wide input voltage range
  - 5V to 28V
- Support Intel  $I_{TDC}$  up to 25A
- Support Intel  $ICC_{MAX}$  up to 50A
- 2 bits programmable output voltage adjustable from 0V to 1.8V
- Integrated high performance trench MOSFETs capable of :
  - High peak current
    - Up to 90A with 10ms on pulse
    - Up to 120A with 10μs on pulse
  - Low  $R_{DS(ON)}$  internal NFETs
    - 5mΩ high-side
    - 0.8mΩ low-side
- Constant On-Time with input feed-forward
- Programmable frequency up to 2.6μs
- Selectable PFM light load operation
- Adjustable load-line compensation
- High accuracy current monitor
- Remote sense
- Ceramic capacitor stable
- Fixed soft-start
- Power Good output
- Integrated bootstrap diode
- Cycle-by-cycle current limit
- Short-circuit protection
- Over voltage protection
- Thermal shutdown
- Thermally enhanced 36-pin 5mm×5mm QFN

## Applications

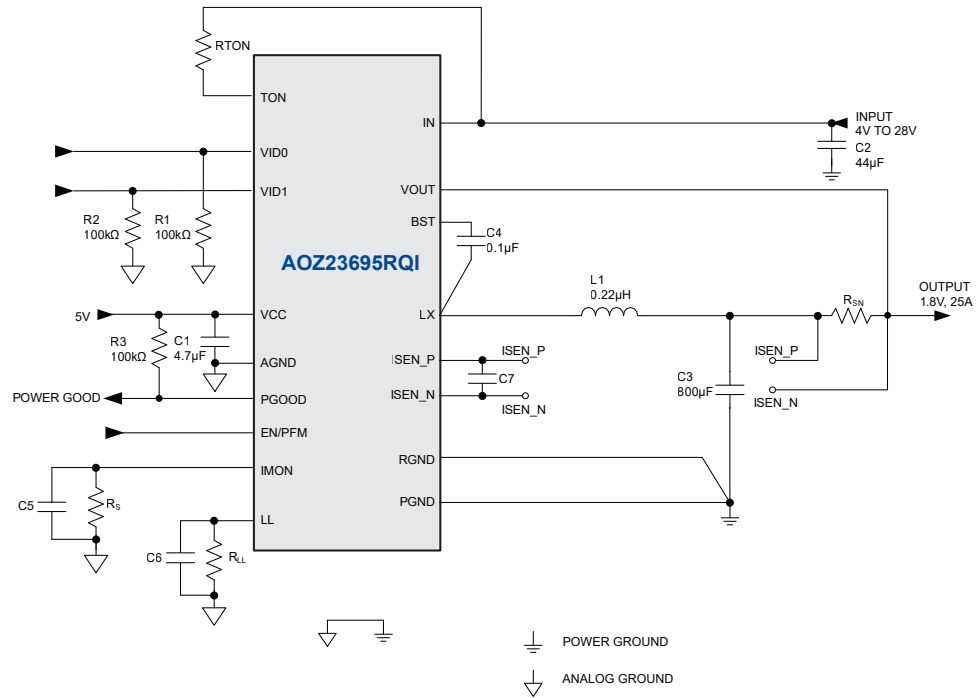
- Portable computers
- Compact desktop PCs
- Servers
- Networking equipment



### IMON 3<sup>rd</sup> Order Thermal Compensation Application (Thermal Compensation only IMON Function)



## IMON Application by Sensing Resistor



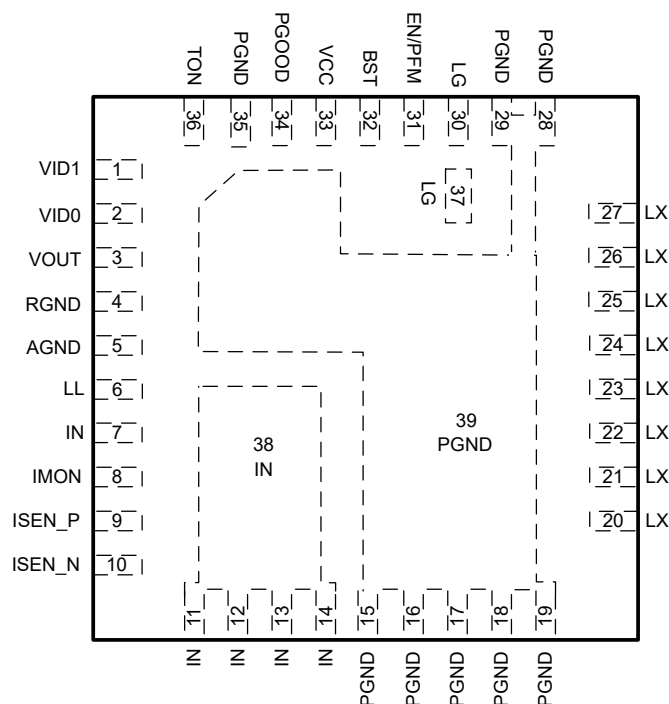
## Ordering Information

| Part Number | Temperature Range | Package        | Environmental |
|-------------|-------------------|----------------|---------------|
| AOZ23695RQI | -40°C to +85°C    | 36-Pin 5×5 QFN | Green         |



AOS products are offered in packages with Pb-free plating and compliant to RoHS standards.  
Please visit <https://aosmd.com/sites/default/files/media/AOSGreenPolicy.pdf> for additional information.

## Pin Configuration



**AOZ23695RQI**  
**36-pin 5mm x 5mm QFN**

## Pin Description

| Pin Number                               | Pin Name | Pin Function   |
|--|----------|--|
| 1  | VID1     | VID Interface.   |
| 2  | VID0     | VID Interface.   |
| 3  | VOUT     | Output Voltage Feedback Input. Connection to the output voltage.   |
| 4  | RGND     | Remote Sensing GND. Connection to GND of the load.   |
| 5  | AGND     | Analog Ground.   |
| 6  | LL       | Loadline setting. Connect a resistor between LL and GND.   |
| 8  | IMON     | Current monitor output. The pin outputs a voltage which is proportional to the loading current.  |
| 9  | ISEN_P   | Positive current sense inputs. Connect to the most positive node of current sense resistor or inductor DCR sense R-C network.  |
| 10                                       | ISEN_N   | Negative current sense inputs. Connect to the most negative node of current sense resistor or inductor DCR sense R-C network.  |
| 7, 11, 12, 13,<br>14, 38                 | IN       | Supply Input. IN is the regulator input. All IN pins must be connected together.   |
| 20, 21, 22, 23,<br>24, 25, 26, 27        | LX       | Switching Node.  |
| 15, 16, 17, 18,<br>19, 28, 29, 35,<br>39 | PGND     | Power Ground.  |
| 30, 37                                   | LG       | Low Side MOSFET Gate Connection. This is for test purposes only.   |
| 31                                       | EN/PFM   | Enable and PFM Selection Input. The AOZ23695RQI is enabled when EN is pulled high. The device shuts down when EN is pulled low. Assert EN to high for power-up after IN and VCC are well supplied. The EN/PFM pin is less than 2.5V for PWM operation. The EN/PFM pin is larger than 2.5V for PFM operation. |
| 32                                       | BST      | Bootstrap Capacitor Connection. The AOZ23695RQI includes an internal bootstrap diode. Connect an external capacitor between BST and LX as shown in Typical Application diagram.  |
| 33                                       | VCC      | Supply Input for analog functions and gate driver supply voltage for power stage. Connect a 5V supply capable of a minimum of 80mA. Bypass VCC to AGND with a 4.7 $\mu$ F~10 $\mu$ F ceramic capacitor. Place the capacitor close to VCC pin.  |
| 34                                       | PGOOD    | Power Good Signal Output. PGOOD is an open-drain output used to indicate the status of the output voltage. It is internally pulled low when the output voltage is 15% lower than the nominal regulation voltage for or higher than 2.2V. PGOOD is pulled low during soft-start and shut down.                |
| 36                                       | TON      | On-Time Setting Input. Connect a resistor between VIN and TON to set the on time.  |

## Absolute Maximum Ratings

Exceeding the Absolute Maximum ratings may damage the device.

| Parameter                              | Rating          |
|--|-----------------|
| IN, TON to AGND                        | -0.3V to 30V    |
| IN to LX <sup>(1)</sup>                | -0.3V to 30V    |
| LX to AGND <sup>(2)</sup>              | -1.0V to 30V    |
| BST to AGND                            | -0.3V to 36V    |
| TON to AGND                            | -0.3V to 30V    |
| PGND to AGND                           | -0.3V to +0.3V  |
| Other Pins to AGND                     | -0.3V to 6V     |
| Junction Temperature (T <sub>J</sub> ) | +150°C          |
| Storage Temperature (T <sub>S</sub> )  | -65°C to +150°C |
| ESD Rating-HBM <sup>(3)</sup>          | 2kV             |
| ESD Rating-CDM                         | 1kV             |

### Notes:

1. IN to LX Transient (t<20ns) ----- -7V to VIN+7V.
2. LX to PGND Transient (t<20ns) ----- -7V to VIN+7V.
3. Devices are inherently ESD sensitive, handling precaution are required. Human body model rating: 1.5kΩ in series with 100pF.

## Recommended Operating Conditions

The device is not guaranteed to operate beyond the Maximum Recommended Operating Conditions.

| Parameter  | Rating            |
|--|-------------------|
| Supply Voltage (V <sub>IN</sub> )                                      | 5V to 28V         |
| Output Voltage Range   | 0V to 1.8V        |
| Ambient Temperature (T <sub>A</sub> )                                  | -40°C to +85°C    |
| Operating Junction Temperature (T <sub>J</sub> )                       | -40°C to +145°C   |
| Package Thermal Resistance<br>(θ <sub>JA</sub> )<br>(θ <sub>JC</sub> ) | 20°C/W<br>2.5°C/W |

## Electrical Characteristics

T<sub>A</sub> = 25°C, V<sub>IN</sub> = 24V, EN = 5V, unless otherwise specified. Specifications in BOLD indicate a temperature range of -40°C to +85°C.

| Symbol                 | Parameter  | Conditions   | Min      | Typ                      | Max        | Unit |
|------------------------|--|--|----------|--------------------------|------------|------|
| V <sub>IN</sub>        | IN Supply Voltage                                  |  | <b>5</b> |                          | <b>28</b>  | V    |
| V <sub>UVLO</sub>      | Under-Voltage Lockout Threshold of V <sub>CC</sub> | V <sub>CC</sub> rising<br>V <sub>CC</sub> falling          |          | <b>4.5</b><br><b>4.1</b> |            | V    |
| I <sub>SLEEP</sub>     | Sleep Mode Supply Current of V <sub>CC</sub>       | I <sub>OUT</sub> = 0A, V <sub>EN</sub> > 2V, VID[1,0] = 00 |          | <b>70</b>                | <b>100</b> | μA   |
| I <sub>OFF</sub>       | Shutdown Supply Current                            | V <sub>EN</sub> = 0V                                       |          | <b>1</b>                 | <b>2</b>   | μA   |
| I <sub>VOUT</sub>      | Output Voltage                                     | VID[1,0] = 00  |          | 0                        |            | V    |
|                        |  | VID[1,0] = 01  |          | 1.1                      |            |      |
|                        |  | VID[1,0] = 10  |          | 1.65                     |            |      |
|                        |  | VID[1,0] = 11  |          | 1.8                      |            |      |
| T <sub>RAMP UP</sub>   | Ramp up Time                                       |  |          |                          | 149        | μs   |
| T <sub>RAMP DOWN</sub> | Ramp down Time                                     | Does not apply for Decay mode                              |          |                          | 149        | μs   |
| <b>VID 0 and VID 1</b> |  |  |          |                          |            |      |
| V <sub>ID</sub>        | VID 0&VID1 Input Threshold                         | Low threshold<br>High threshold                            | 2.0      |                          | 0.3        | V    |
| V <sub>ID_HYS</sub>    | VID 0&VID1 Input Hysteresis                        |  |          | 300                      |            | mV   |
| <b>Modulator</b>       |  |  |          |                          |            |      |
| f <sub>SW</sub>        | Operating Frequency                                | R <sub>TON</sub> = 120kΩ                                   |          | 600                      |            | kHz  |

## Electrical Characteristics

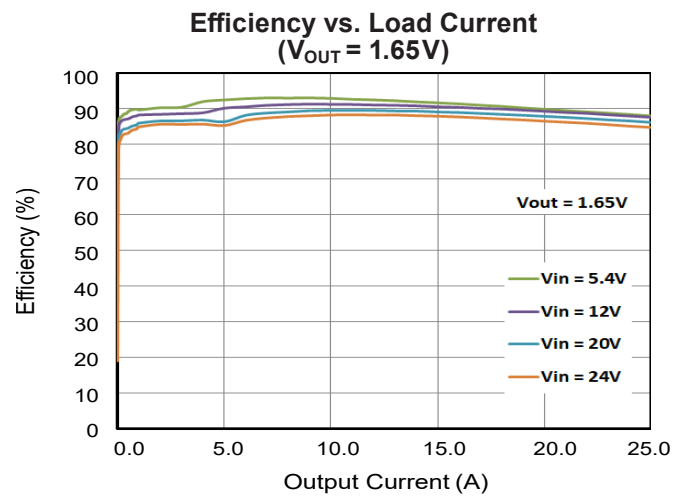
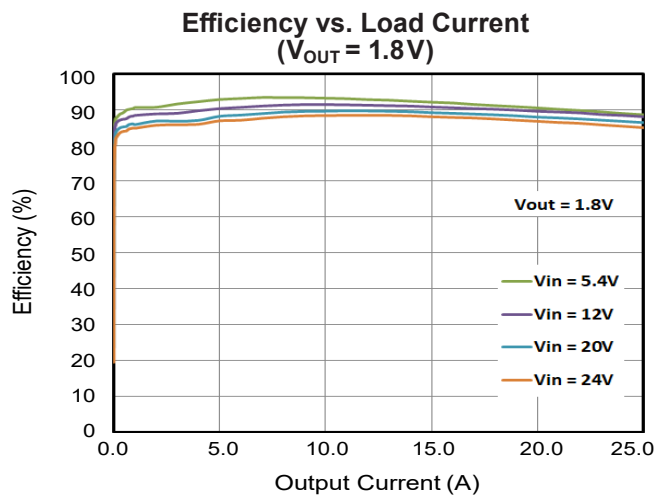
$T_A = 25^\circ\text{C}$ ,  $V_{IN} = 24\text{V}$ ,  $V_{EN} = 5\text{V}$ , unless otherwise specified. Specifications in BOLD indicate a temperature range of  $-40^\circ\text{C}$  to  $+85^\circ\text{C}$ .

| Symbol   | Parameter                                 | Conditions   | Min | Typ       | Max     | Unit             |
|--|---|--|-----|-----------|---------|------------------|
| <b>Modulator</b>                                 |   |  |     |           |         |                  |
| $T_{ON}$   | Normal On Time                            | $V_{IN} = 12\text{V}$ , $VID[1,0] = 01$            |     | 150       |         | ns               |
|  |   | $V_{IN} = 12\text{V}$ , $VID[1,0] = 10$            |     | 230       |         |                  |
|  |   | $V_{IN} = 12\text{V}$ , $VID[1,0] = 11$            |     | 250       |         |                  |
| $T_{ON\_MIN}$                                    | Minimum On Time                           |  |     | 70        |         |                  |
| $T_{OFF\_MIN}$                                   | Minimum Off Time                          |  |     | 400       |         |                  |
| <b>Soft-Start</b>                                |   |  |     |           |         |                  |
| $T_{SS\_OUT}$                                    | SS time                                   | For PGOOD signal is pulled high.                   |     | 1.5       |         | ms               |
| <b>Power Good Signal</b>                         |   |  |     |           |         |                  |
| $V_{PG\_LOW}$                                    | PGOOD Low Voltage                         | $I_{OL} = 1\text{mA}$                              |     |           | 0.5     | V                |
|  | PGOOD Leakage Current                     |  |     |           | $\pm 1$ | $\mu\text{s}$    |
| $V_{PGH}$  | PGOOD Threshold (Low level to High level) | VOUT rising  |     | 90        |         | %                |
| $V_{PGL}$  | PGOOD Threshold (High level to Low level) | VOUT rising (over $5\mu\text{s}$ )<br>VOUT falling |     | 2.2<br>85 |         | V<br>%           |
|  | PGOOD Threshold Hysteresis                |  |     | 5         |         | %                |
| $T_{PG\_DB}$                                     | De-bounce Time for PGOOD                  | PGOOD signal from low to high                      |     | 20        | 30      | $\mu\text{s}$    |
| <b>Under Voltage and Over Voltage Protection</b> |   |  |     |           |         |                  |
| $V_{PL}$   | Under Voltage threshold                   | VOUT falling                                       |     | 50        |         | %                |
| $V_{PH}$   | Over Voltage Threshold                    | VOUT rising  |     | 2.2       |         | V                |
| <b>Power Stage Output</b>                        |   |  |     |           |         |                  |
| $R_{DS(ON)}$                                     | High-Side NFET On- Resistance             | $V_{IN} = 12\text{V}$ , $V_{CC} = 5\text{V}$       |     | 5         |         | $\text{m}\Omega$ |
|  | High-Side NFET Leakage                    | $V_{EN} = 0\text{V}$ , $V_{LX} = 0$                |     |           | 10      | $\mu\text{A}$    |
| $R_{DS(ON)}$                                     | Low-Side NFET On- Resistance              | $V_{LX} = 12\text{V}$ , $V_{CC} = 5\text{V}$       |     | 0.8       |         | $\text{m}\Omega$ |
|  | Low-Side NFET Leakage                     | $V_{EN} = 0\text{V}$                               |     |           | 10      | $\mu\text{A}$    |
| <b>Enable</b>                                    |   |  |     |           |         |                  |
| $V_{EN}$   | EN Input Threshold                        | Off threshold<br>On threshold                      | 1.3 |           | 0.6     | V                |
| $V_{EN\_HYS}$                                    | EN Input Hysteresis                       |  |     | 300       |         | mV               |
| <b>Over-current and Thermal Protection</b>       |   |  |     |           |         |                  |
| $I_{LIM\_SC}$                                    | Source Current Limit                      | $V_{CC} = 5\text{V}$                               | 60  | 65        |         | A                |
| $I_{LIM\_Sk}$                                    | Sink Current Limit                        | $V_{CC} = 5\text{V}$                               | 24  |           |         | A                |
|  | Thermal Shutdown Threshold                | $T_J$ rising                                       |     | 150       |         | $^\circ\text{C}$ |





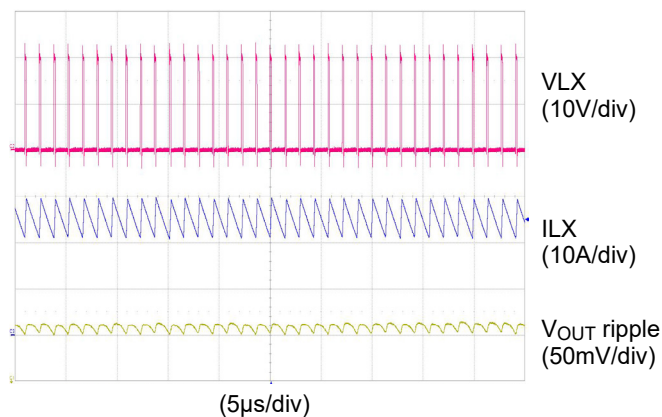
## Typical Performance Characteristics



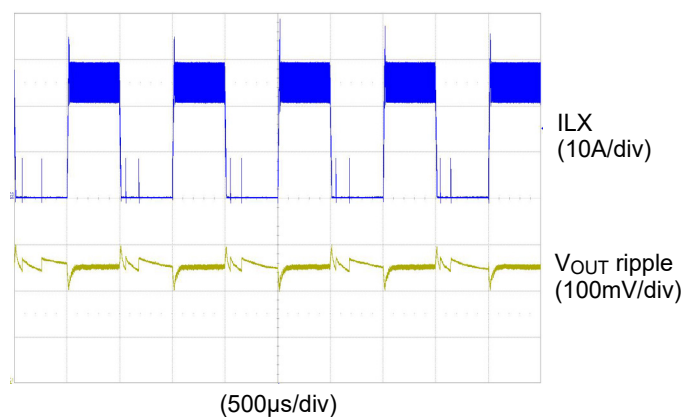
## Typical Performance Characteristics

$T_A = 25^\circ\text{C}$ ,  $V_{IN} = 20\text{V}$ ,  $V_{OUT} = 1.8\text{V}$ , (VID[1:0] = 11),  $L = 0.22\mu\text{H}$ , unless otherwise specified.

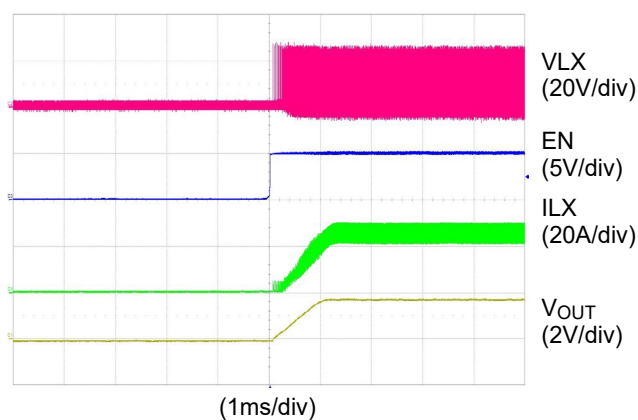
Normal Operation



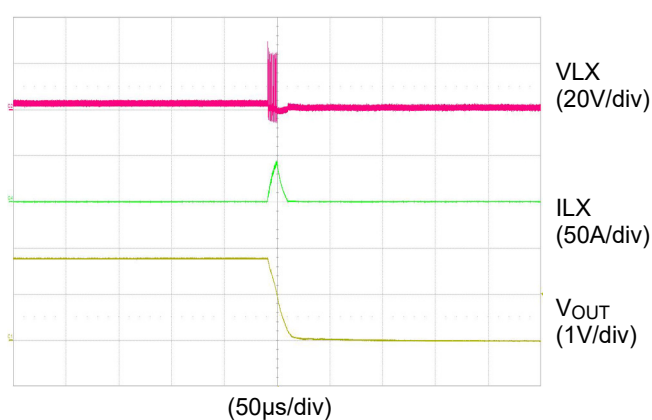
Load Transient 0A to 25A



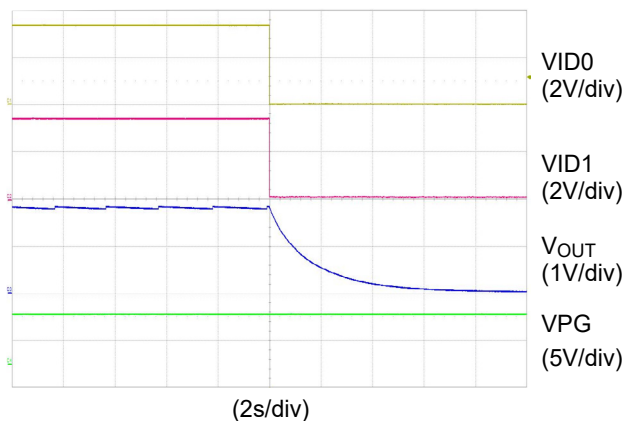
Full Load Start-up



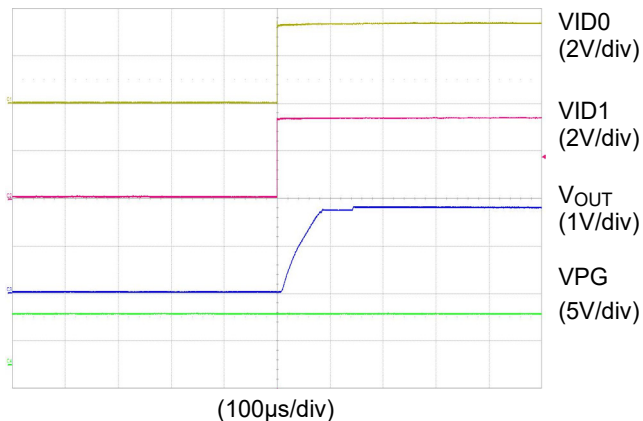
Short Circuit Protection



VID Change 1.8V to 0V



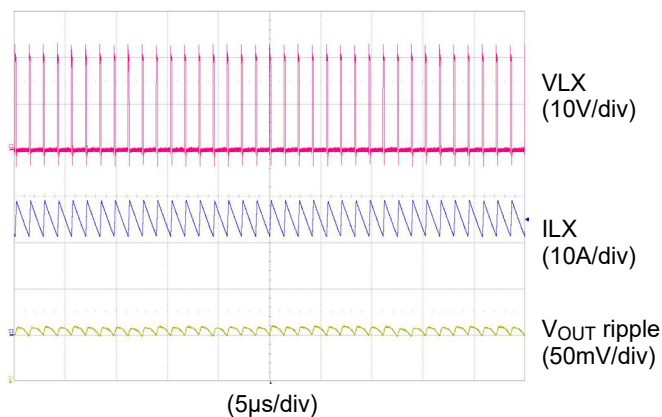
VID Change 0V to 1.8V



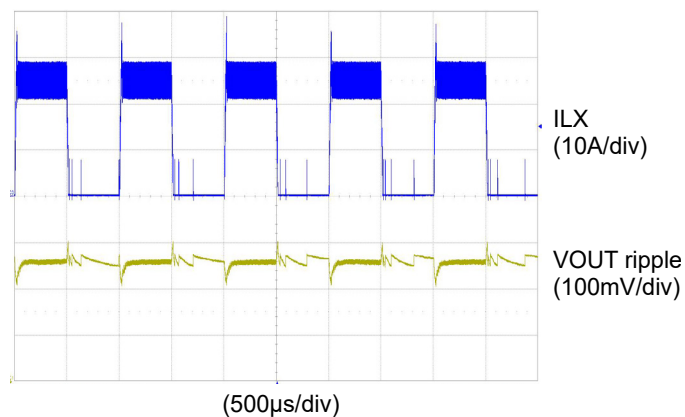
## Typical Performance Characteristics

$T_A = 25^\circ\text{C}$ ,  $V_{IN} = 20\text{V}$ ,  $V_{OUT} = 1.65\text{V}$ , (VID[1:0] = 10),  $L = 0.22\mu\text{H}$ , unless otherwise specified.

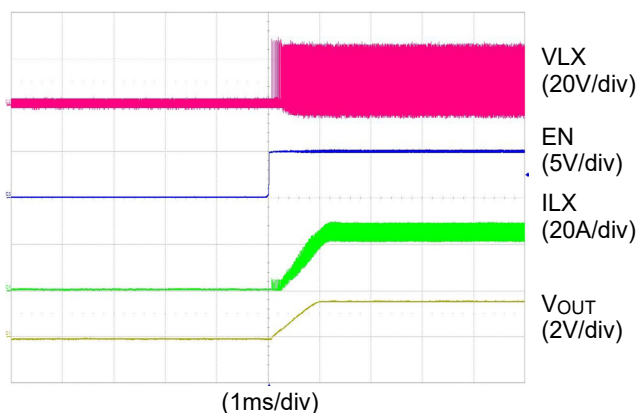
**Normal Operation**



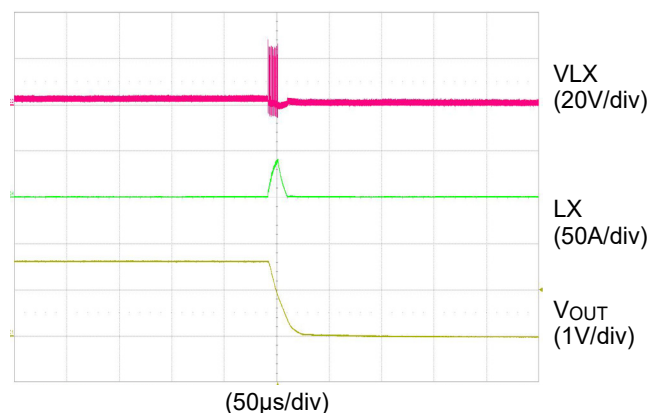
**Load Transient 0A to 25A**



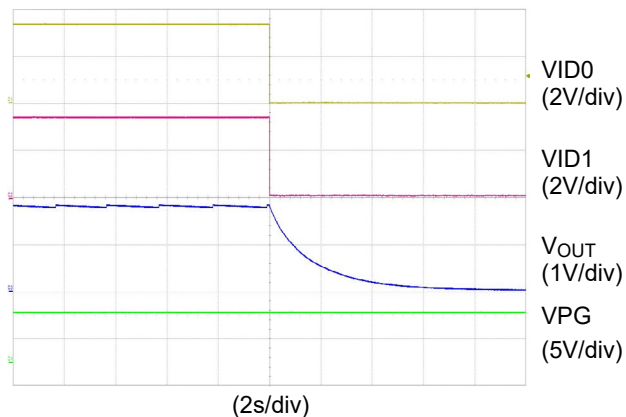
**Full Load Start-up**



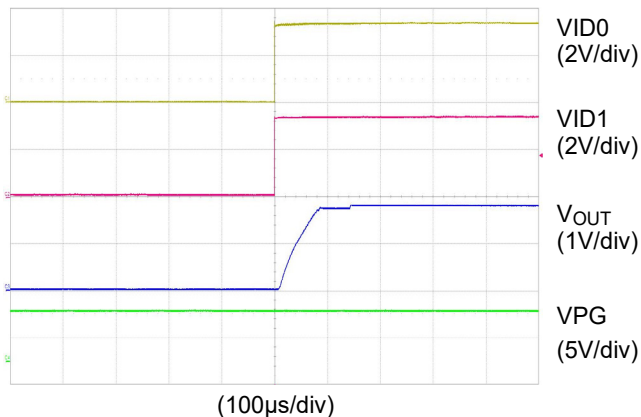
**Short Circuit Protection**



**VID Change 1.65V to 0V**



**VID Change 0V to 1.65V**



## Detailed Description

The AOZ23695RQI is a high-efficiency, easy-to-use DC/DC synchronous buck regulator capable of operation from a 4V to 28V input bus. The device is capable of supplying 25A of continuous output current with an output voltage adjustment from 0V to 1.8V by controlling VID0 and VID1 signals.

Constant on-time PWM with input feed-forward control scheme results in ultra-fast transient response while maintaining relatively constant switching frequency over the entire input range. True AC current mode control scheme guarantees the regulators can be stable with ceramics output capacitor. Protection features include  $V_{CC}$  under-voltage lockout, cycle-by-cycle current limit, output over voltage and under voltage protection, short-circuit protection, and thermal shutdown.

The AOZ23695RQI is available in 36-pin 5mm×5mm QFN package.

### Enable and Soft-Start

The AOZ23695RQI has internal soft-start feature to limit in-rush current and ensure the output voltage ramps up smoothly to regulate voltage. A soft-start process begins when  $V_{CC}$  rises to 4.5V and voltage on EN pin is HIGH. The output voltage follows the internal voltage of soft-start ( $V_{SS}$ ) when it is lower than initial output voltage. When  $V_{SS}$  is higher than initial output voltage, the voltage of VOUT pin is regulated by internal precise band-gap voltage. Moreover, the soft-start period between EN and PGOOD is 1.5ms. The soft-start sequence of AOZ23695RQI is shown in Figure 1.

The AOZ23695RQI has the auto-skip mode control function to achieve higher efficiency at light load condition. When the output current decreases, the inductor current also reduces. If the inductor current valley point reaches to zero current, the AOZ23695RQI operates at auto-skip mode. It means the zero current is the boundary between pulse-width mode and auto-skip mode. As the inductor current reaches to zero current, the low-side MOSFET is turned off, and then the AOZ23695RQI operates at tri-state for auto-skip mode. Until output voltage is less than reference voltage, the on time signal is triggered to turn on high-side MOSFET.

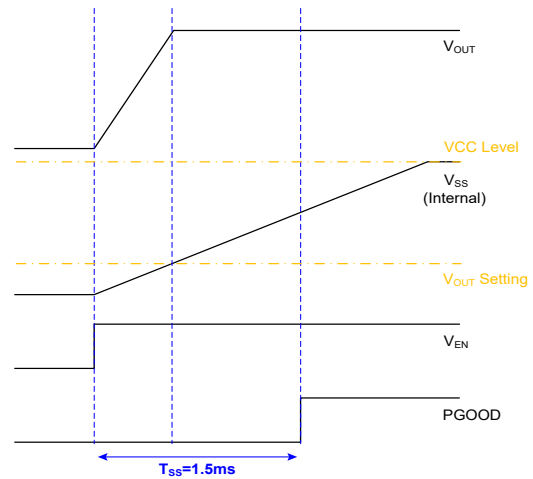


Figure 1. Soft-Start Sequence of AOZ23695RQI

The EN/PFM pin provides the 3 different levels of EN and PFM for flexible design. Table 1 shows the recommended voltage for corresponding mode.

Table 1. EN/PFM Pin Voltage for Corresponding Setting

| State  | EN/PFM Pin Voltage       | Condition              |
|--------|--------------------------|------------------------|
| Mode 1 | EN/PFM pin < 1.3V        | EN Disable             |
| Mode 2 | 1.3V < EN/PFM pin < 2.5V | EN Enable and PWM Mode |
| Mode 3 | EN/PFM pin > 2.5V        | EN Enable and PFM Mode |

### Constant-On-Time PWM Control with Input Feed-Forward

The control algorithm of AOZ23695RQI is constant-on-time PWM Control with input feed-forward.

The simplified control schematic is shown in Figure 2. The high-side switch on-time is determined solely by a one-shot whose pulse width is inversely proportional to input voltage (IN). The one-shot is triggered when the internal setting output voltage is higher than the combined information of output voltage and the AC current information of inductor and load line signal, which is processed and obtained through the sensed low-side MOSFET current once it turns on. The added AC current information can help the stability of constant-on time control even with pure ceramic output capacitors, which have very low ESR. The AC current information has no DC offset, which does not cause offset with output load change, which is fundamentally different from other  $V^2$  constant-on time control schemes.

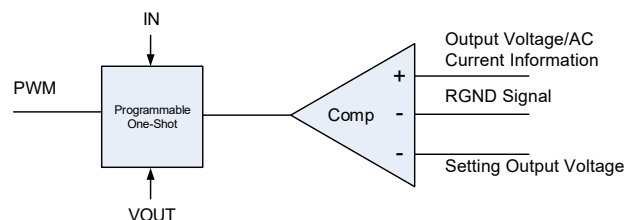


Figure 2. Simplified Control Schematic of AOZ23695R

The constant-on-time PWM control architecture is a pseudo-fixed frequency with input voltage feed-forward. The internal circuit of AOZ23695RQI sets the on-time of high-side switch inversely proportional to the IN.

$$T_{on} \propto \frac{R_{ton}(\Omega)}{V_{in}(V)} \quad (1)$$

To achieve the flux balance of inductor, the buck converter has the equation:

$$F_{sw} = \frac{V_{out}}{V_{in} \cdot T_{on}} \quad (2)$$

Once the product of  $V_{in} \cdot T_{on}$  is constant, the switching frequency keeps constant and is independent of input voltage.

An external resistor between the IN and TON pins sets the switching on-time according to the following curves:

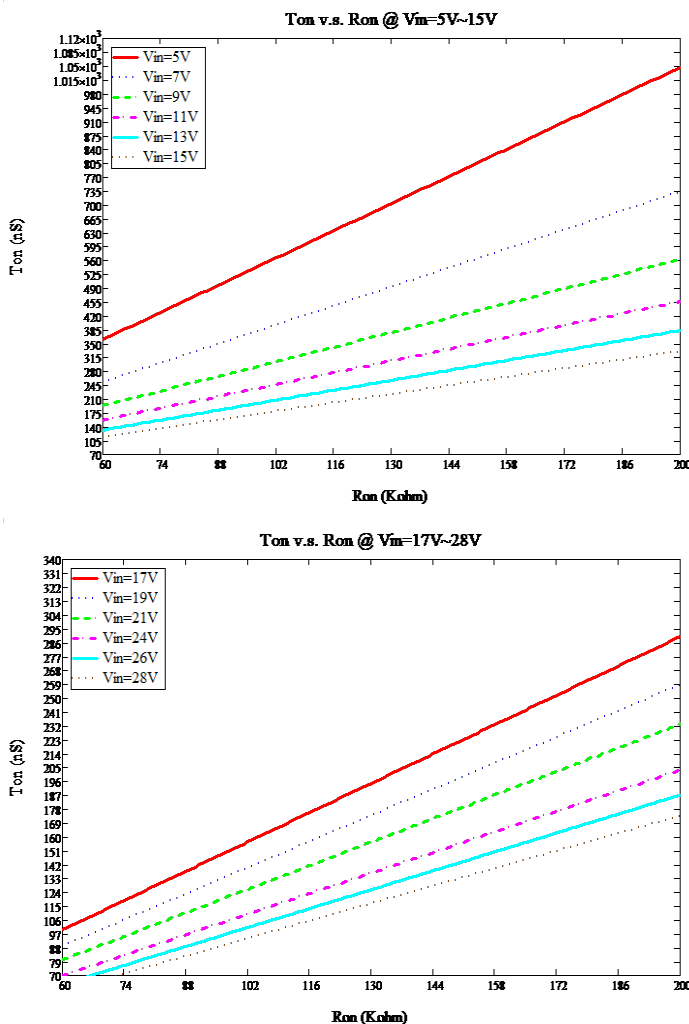


Figure 3. Ton vs. Rton Curves for AOZ23695RQI

A further simplified equation will be

$$F_{sw}(KHz) = \frac{V_{out}(V)}{V_{in}(V) \cdot T_{on}(ns)} \cdot 10^6 \quad (4)$$

If  $V_{OUT}$  is 1.8V,  $V_{in}$  is 13V, and set  $F_s = 600$ kHz. According to eq.(4),  $T_{on} = 230$ ns is needed. Finally, use the  $T_{on}$  to  $R_{on}$  curve, we can find out  $R_{on}$  is 120k $\Omega$ .

This algorithm results in a nearly constant switching frequency despite the lack of a fixed-frequency clock generator.

When the switching frequency is fixed at  $V_{OUT} = 1.8$ V, the switching frequency of other output voltage level is also fixed to the same switching frequency as the  $V_{OUT} = 1.8$ V one.

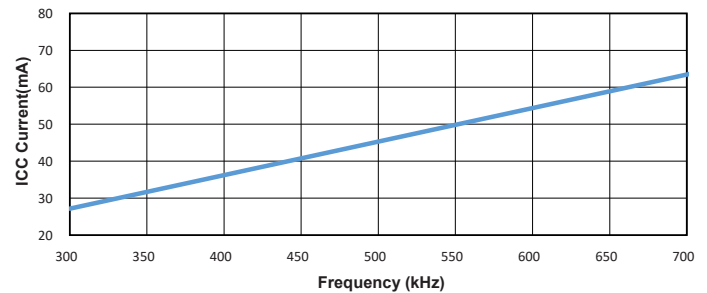


Figure 4. Required ICC Capability vs. Frequency

### True Current Mode Control

The constant-on-time control scheme is intrinsically unstable if output capacitor's ESR is not large enough as an effective current-sense resistor. Ceramic capacitors usually cannot be used as output capacitor.

The AOZ23695RQI senses the low-side MOSFET current and processes it into DC current and AC current information using AOS proprietary technique. The AC current information is decoded and added on the FB pin on phase. With AC current information, the stability of constant-on-time control is significantly improved even without the help of output capacitor's ESR; and thus the pure ceramic capacitor solution can be applicable. The pure ceramic capacitor solution can significantly reduce the output ripple (no ESR caused overshoot and undershoot) and less board area design.

### Decay Mode

The AOZ23695RQI has the decay mode function to implement power saving when there are frequent transitions from higher output voltage to lower one, the regulator output stops switching and goes high impedance. The output naturally decays into the load. The decay mode illustration is shown in Figure 5.

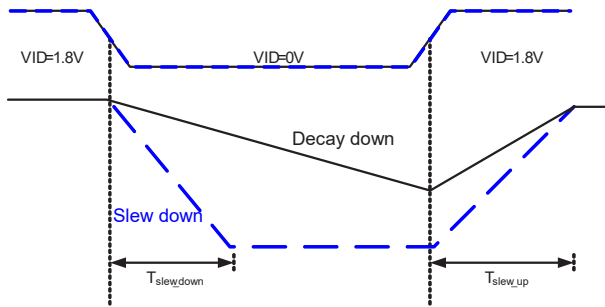


Figure 5. Decay Mode Illustration

## 2 Bits Programmable VID

The AOZ23695RQI implements an output voltage adjustment by controlling VID0 and VID1 signals. Table 2 shows the output voltage for corresponding VID setting.

Table 2. Output Voltage for Corresponding VID Setting

| VOUT Setting | VID0 | VID1 |
|--------------|------|------|
| 1.8V         | 1    | 1    |
| 1.65V        | 0    | 1    |
| 1.1V         | 1    | 0    |
| 0V           | 0    | 0    |

## Current Monitor

The AOZ23695RQI includes a current monitor (IMON) function. The current monitor puts out an analog voltage proportional to the output current on the IMON pin. The current monitor function is determined with the DCR sensing circuit. Considering the DCR thermal effect, the IMON circuit uses the NTC resistor to improve the IMON accuracy to cover the DCR variation.

## Load-Line

The load-line function can be set by load-line resistor. Load-line is used to save on output capacitor and improve the overshoot/undershoot at load transient condition.

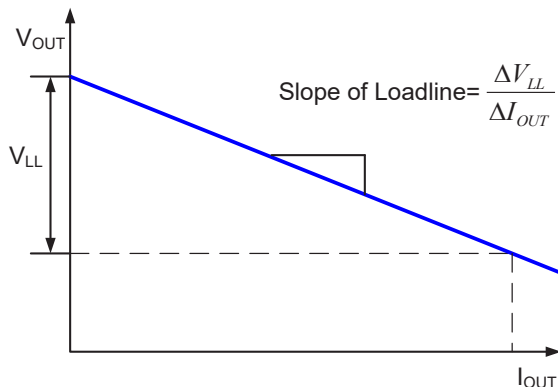


Figure 6. Load-line Illustration

## Remote Sensing Function

The AOZ23695RQI provides the remote sensing function to implement better load regulation in high current application. The VOUT and RGND pins need to connect to the load terminal by kelvin-sensing method. It can compensate the voltage drop from PCB ESR to the setting output voltage that we want. The remote sensing traces (VOUT and RGND return trace) should be far away against from switching signals and high current paths on PCB application. Figure 7 shows the remote sensing connection.

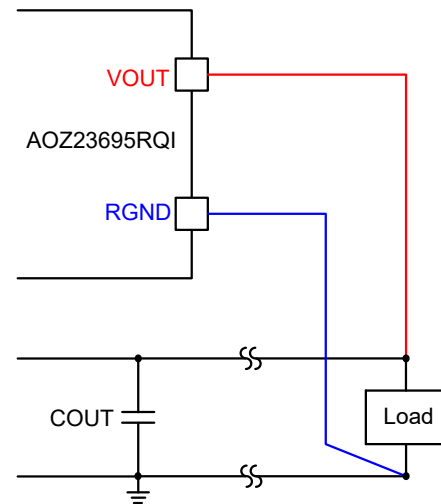


Figure 7. Remote Sensing Connection

## Current-Limit Protection

The AOZ23695RQI has the current-limit protection by using  $R_{ds(on)}$  of the low-side MOSFET to be as current sensing. To detect real current information, a minimum constant off time (400ns typical) is implemented after a constant-on time. If the current exceeds the current-limit threshold, the PWM controller is not allowed to initiate a new cycle. The actual peak current is greater than the current-limit threshold by an amount equal to the inductor ripple current. Therefore, exact current-limit characteristic and maximum load capability are a function of the inductor value and input and output voltages. The current limit will keep the low-side MOSFET on and will not allow another high-side on-time, until the current in the low-side MOSFET reduces below the current limit.

After 16 switching cycles, the AOZ23695RQI considers this is a true failed condition and thus turns-off both high-side and low-side MOSFET and latches off. Only trigger the enable again can restart the AOZ23695RQI.



### Output Voltage Under-voltage Protection

If the output voltage is lower than 50% by over-current or short circuit, AOZ23695RQI turns-off both high-side and low-side MOSFET and latches off. Only trigger the enable again can restart the AOZ23695RQI.

### Output Voltage Over-voltage Protection

The threshold of OVP is set on 2.2V. When the output voltage exceeds the OVP threshold, high-side and low-side MOSFET are turned-off. If the time is over 5μs for the output voltage is higher than the OVP threshold, AOZ23695RQI is latched-off. Only trigger the enable again can restart the AOZ23695RQI.

### Power Good Output

The power good (PGOOD) output, which is an open drain output, requires the pull-up resistor. When the output voltage is 15% below than the nominal regulation voltage for, the PGOOD is pulled low. When the output voltage is higher than 2.2V, the PGOOD is also pulled low.

When combined with the under-voltage-protection circuit, this current-limit method is effective in almost every circumstance.

## Application Information

The basic AOZ23695RQI application circuit is shown in Typical Application diagram. Component selection is explained below.

### Input Capacitor

The input capacitor must be connected to the IN pins and PGND pin of the AOZ23695RQI to maintain steady input voltage and filter out the pulsing input current. A small decoupling capacitor, usually 4.7μF, should be connected to the VCC pin and AGND pin for stable operation of the AOZ23695RQI. The voltage rating of input capacitor must be greater than maximum input voltage plus ripple voltage.

The input ripple voltage can be approximated by equation below:

$$\Delta V_{IN} = \frac{I_{OUT}}{f \times C_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times \frac{V_{OUT}}{V_{IN}}$$

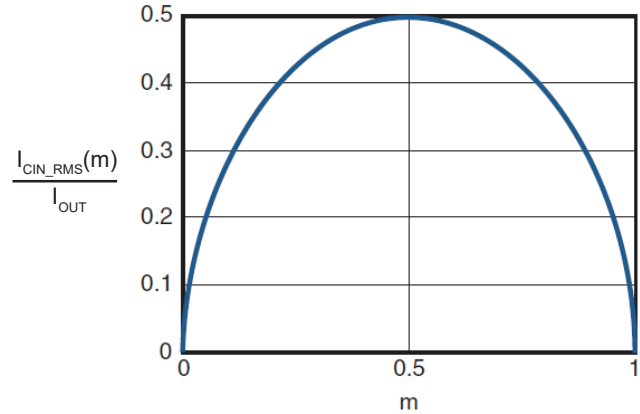
Since the input current is discontinuous in a buck converter, the current stress on the input capacitor is another concern when selecting the capacitor. For a buck circuit, the RMS value of input capacitor current can be calculated by:

$$I_{CIN\_RMS} = I_{OUT} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \left(1 - \frac{V_{OUT}}{V_{IN}}\right)}$$

If let m equal the conversion ratio:

$$\frac{V_{OUT}}{V_{IN}} = m$$

The relation between the input capacitor RMS current and voltage conversion ratio is calculated and shown in Figure 8 below. It can be seen that when  $V_{OUT}$  is half of  $V_{IN}$ ,  $C_{IN}$  is under the worst current stress. The worst current stress on  $C_{IN}$  is  $0.5 \cdot I_{OUT}$ .



**Figure 8.  $I_{CIN}$  vs. Voltage Conversion Ratio**

For reliable operation and best performance, the input capacitors must have current rating higher than  $I_{CIN\_RMS}$  at worst operating conditions. Ceramic capacitors are preferred for input capacitors because of their low ESR and high ripple current rating. Depending on the application circuits, other low ESR tantalum capacitor or aluminum electrolytic capacitor may also be used. When selecting ceramic capacitors, X5R or X7R type dielectric ceramic capacitors are preferred for their better temperature and voltage characteristics. Note that the ripple current rating from capacitor manufactures is based on certain amount of life time. Further de-rating may be necessary for practical design requirement.

### Inductor

The inductor is used to supply constant current to output when it is driven by a switching voltage. For given input and output voltage, inductance and switching frequency together decide the inductor ripple current, which is,

$$\Delta I_L = \frac{V_{OUT}}{f \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

The peak inductor current is:

$$I_{L_{peak}} = I_{OUT} + \frac{\Delta I_L}{2}$$

High inductance gives low inductor ripple current but requires larger size inductor to avoid saturation. Low ripple current reduces inductor core losses. It also reduces RMS current through inductor and switches, which results in less conduction loss. Usually, peak to peak ripple current on inductor is designed to be 30% to 50% of output current.

When selecting the inductor, make sure it is able to handle the peak current without saturation even at the highest operating temperature.

AOZ23695RQI is designed for fast transient application, like VRTT testing. So 0.22μH and 0.15μH inductance is the best choice. For better IMON accuracy, the inductor DCR must be larger than 0.9mΩ.

The inductor takes the highest current in a buck circuit. The conduction loss on inductor needs to be checked for thermal and efficiency requirements.

Surface mount inductors in different shape and styles are available from Coilcraft, Elytone and Murata. Shielded inductors are small and radiate less EMI noise. But they cost more than unshielded inductors. The choice depends on EMI requirement, price and size.

### Output Capacitor

The output capacitor is selected based on the DC output voltage rating, output ripple voltage specification and ripple current rating.

The selected output capacitor must have a higher rated voltage specification than the maximum desired output voltage including ripple. De-rating needs to be considered for long term reliability.

Output ripple voltage specification is another important factor for selecting the output capacitor. In a buck converter circuit, output ripple voltage is determined by inductor value, switching frequency, output capacitor value and ESR. It can be calculated by the equation below:

$$\Delta V_{OUT} = \Delta I_L \times (ESR_{COUT} + \frac{1}{8 \times f \times C_{OUT}})$$

Where COUT is the output capacitor value and ESR<sub>COUT</sub> is the Equivalent Series Resistor of output capacitor.

When low ESR ceramic capacitor is used as output capacitor, the impedance of the capacitor at the switching frequency dominates. Output ripple is mainly caused by capacitor value and inductor ripple current. The output ripple voltage calculation can be simplified to:

$$\Delta V_{OUT} = \Delta I_L \times \frac{1}{8 \times f \times C_{OUT}}$$

If the impedance of ESR at switching frequency dominates, the output ripple voltage is mainly decided by capacitor ESR and inductor ripple current. The output ripple voltage calculation can be further simplified to:

$$\Delta V_{OUT} = \Delta I_L \times ESR_{COUT}$$

For lower output ripple voltage across the entire operating temperature range, X5R or X7R dielectric type of ceramic, or other low ESR tantalum are recommended to be used as output capacitors.

In a buck converter, output capacitor current is continuous. The RMS current of output capacitor is decided by the peak to peak inductor ripple current. It can be calculated by:

$$I_{COUT\_RMS} = \frac{\Delta I_L}{\sqrt{12}}$$

Usually, the ripple current rating of the output capacitor is a smaller issue because of the low current stress. When the buck inductor is selected to be very small and inductor ripple current is high, output capacitor could be overstressed. The recommended output capacitance is 800μF for fast transient and VID change application. Larger output capacitance possible cause larger inrush current when VID change, therefore, output capacitance need to carefully estimate.

### Power MOSFET SOA Curve

AOZ23695RQI integrates AOS's state of the art Trench MOSFETs. Robust SOA ensures reliable operation in high performance buck regulator applications.



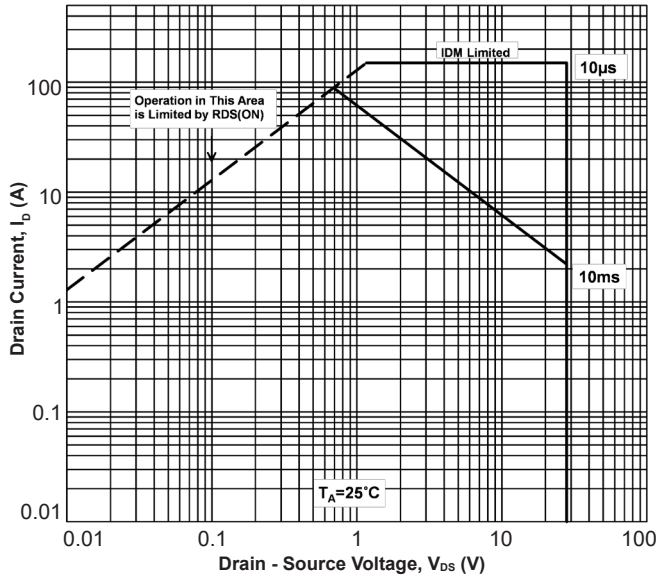


Figure 9. High-Side MOSFET SOA Curve

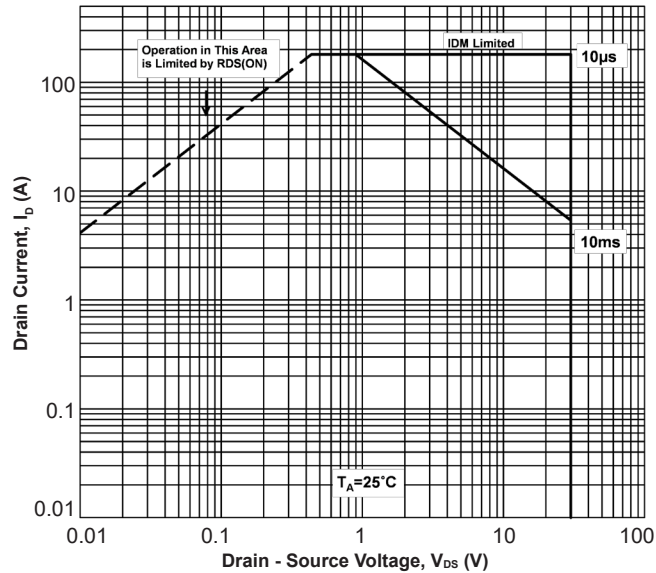


Figure 10. Low-Side MOSFET SOA Curve

## Thermal Management and Layout Consideration

In the AOZ23695RQI buck regulator circuit, high pulsing current flows through two circuit loops. The first loop starts from the input capacitors, to the VIN pin, to the LX pins, to the filter inductor, to the output capacitor and load, and then return to the input capacitor through ground. Current flows in the first loop when the high-side switch is on. The second loop starts from inductor, to the output capacitors and load, to the low-side switch. Current flows in the second loop when the low-side switch is on.

In PCB layout, minimizing the two loops area reduces the noise of this circuit and improves efficiency. A ground plane is strongly recommended to connect input capacitor, output capacitor, and PGND pin of the AOZ23695RQI.

In the AOZ23695RQI buck regulator circuit, the major power dissipating components are the AOZ23695RQI and the output inductor. The total power dissipation of converter circuit can be measured by input power minus output power.

$$P_{total\_loss} = V_{IN} \cdot I_{IN} - V_{OUT} \cdot I_{OUT}$$

The power dissipation of inductor can be approximately calculated by DCR of inductor and output current.

$$P_{inductor\_loss} = I_{OUT}^2 \cdot R_{inductor} \cdot 1.1$$

The actual junction temperature can be calculated with power dissipation in the AOZ23695RQI and thermal impedance from junction to ambient.

$$T_{junction} = (P_{total\_loss} - P_{inductor\_loss}) \cdot \theta_{JA} + T_A$$

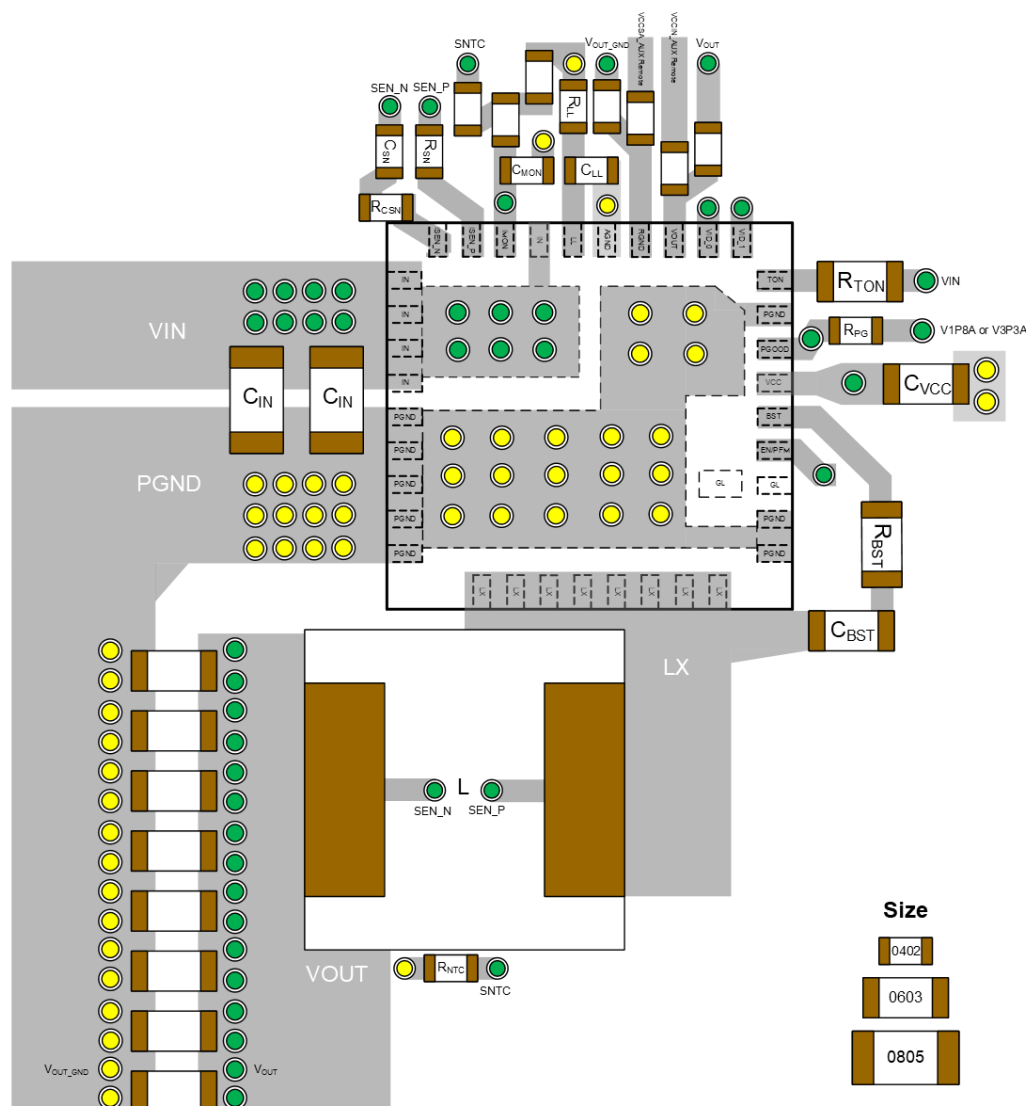
The maximum junction temperature of AOZ23695RQI is 150°C, which limits the maximum load current capability.

The thermal performance of the AOZ23695RQI is strongly affected by the PCB layout. Extra care should be taken by users during the design process to ensure that the IC will operate under the recommended environmental conditions.

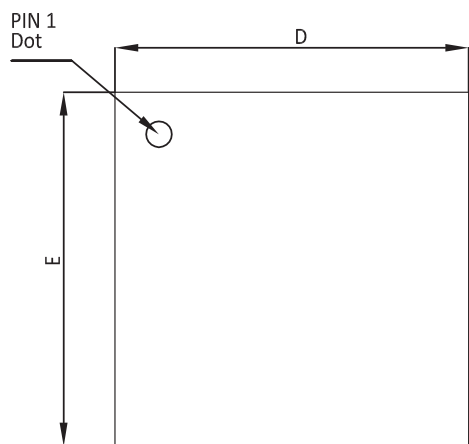
## Layout Considerations

Several layout tips are listed below for the best electric and thermal performance.

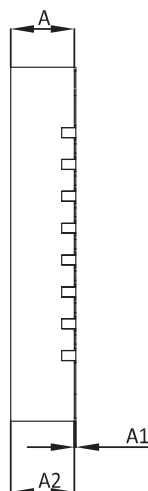
1. Connected a small copper plane to LX pin to have lower noise interference area.
2. The IN pins and pad are connected to internal high side switch drain. They are also low resistance thermal conduction path. Connected a large copper plane to IN pins to help thermal dissipation.
3. Input capacitors should be connected to the IN pin and the PGND pin as close as possible to reduce the switching spikes.
4. Decoupling capacitor CVCC should be connected to VCC and AGND as close as possible.
5. DCR sensing capacitor CSN should be connected to ISEN\_P and ISEN\_N as close as possible.
6. Keep sensitive signal traces such as output trace and RGND trace far away from the LX pins.
7. Let VID0, VID1, LL, and IMON pin to use AGND. Pour copper plane on all unused board area and connect it to stable DC nodes, like VIN, GND or VOUT.
8. Do Not connect the LX plane by any VIAS to avoid the noise couple.
9. The GND terminal of VCC decoupling capacitor, should be single connect to GND plane by VIAS.



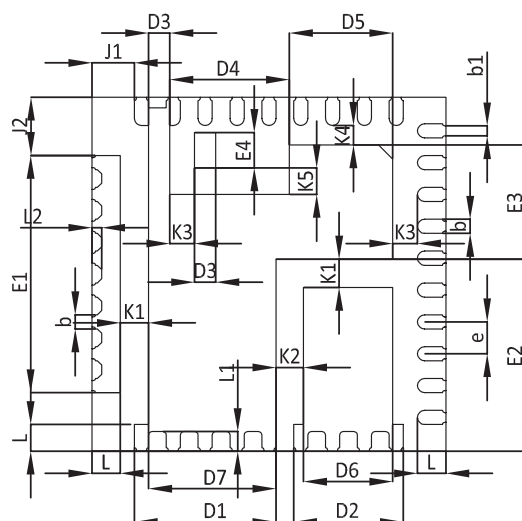
## Package Dimensions, QFN5x5-36L



TOP VIEW



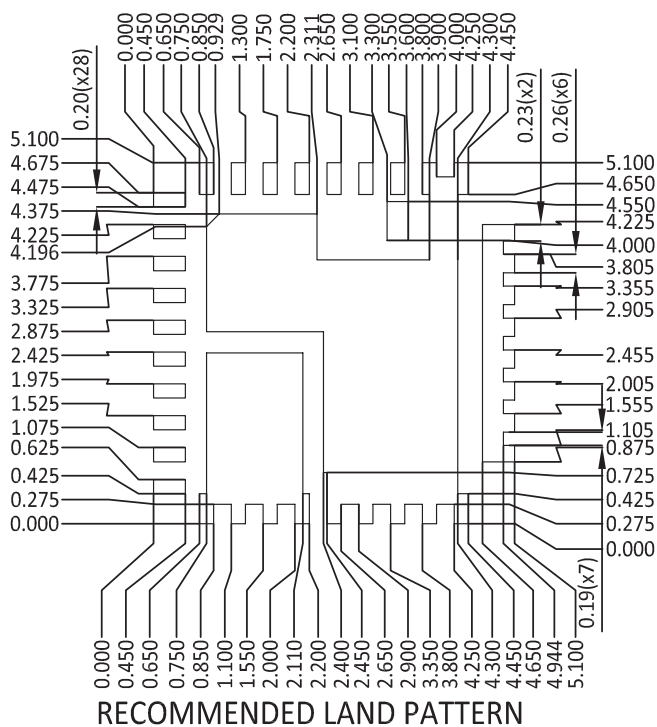
SIDE VIEW



BOTTOM VIEW



SIDE VIEW



RECOMMENDED LAND PATTERN

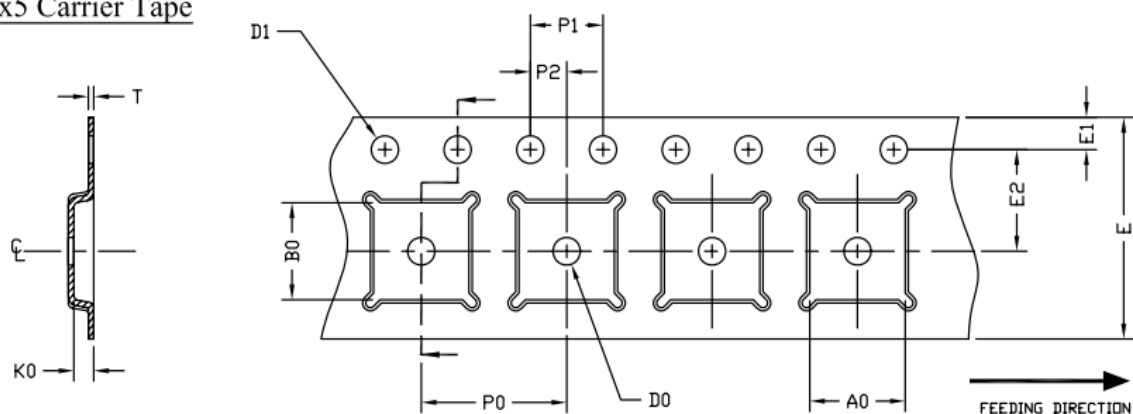
| SYMBOLS | DIM. IN MM |      |      | DIM. IN INCH |       |       |
|---------|------------|------|------|--------------|-------|-------|
|         | MIN.       | NOM. | MAX. | MIN.         | NOM.  | MAX.  |
| A       | 0.80       | 0.90 | 1.00 | 0.031        | 0.035 | 0.039 |
| A1      | 0.00       | ---  | 0.05 | 0.000        | ---   | 0.002 |
| A2      | 0.20 REF   |      |      | 0.008 REF    |       |       |
| D       | 4.90       | 5.00 | 5.10 | 0.193        | 0.197 | 0.201 |
| D1      | 1.95       | 2.00 | 2.05 | 0.077        | 0.079 | 0.081 |
| D2      | 1.50       | 1.55 | 1.60 | 0.059        | 0.061 | 0.063 |
| D3      | 0.25       | 0.30 | 0.35 | 0.010        | 0.012 | 0.014 |
| D4      | 1.64       | 1.69 | 1.74 | 0.065        | 0.067 | 0.069 |
| D5      | 1.41       | 1.46 | 1.51 | 0.056        | 0.057 | 0.059 |
| D6      | 1.21       | 1.26 | 1.31 | 0.048        | 0.050 | 0.052 |
| D7      | 1.75       | 1.80 | 1.85 | 0.069        | 0.071 | 0.073 |
| E       | 4.95       | 5.00 | 5.05 | 0.195        | 0.197 | 0.199 |
| E1      | 3.25       | 3.35 | 3.45 | 0.128        | 0.132 | 0.136 |
| E2      | 2.61       | 2.71 | 2.81 | 0.103        | 0.107 | 0.111 |
| E3      | 1.51       | 1.61 | 1.71 | 0.059        | 0.063 | 0.067 |
| E4      | 0.40       | 0.50 | 0.60 | 0.016        | 0.020 | 0.024 |
| L       | 0.35       | 0.40 | 0.45 | 0.014        | 0.016 | 0.018 |
| L1      | 0.23       | 0.28 | 0.33 | 0.009        | 0.011 | 0.013 |
| L2      | 0.09       | 0.14 | 0.19 | 0.004        | 0.006 | 0.007 |
| J1      | 0.55       | 0.60 | 0.65 | 0.022        | 0.024 | 0.026 |
| J2      | 0.78       | 0.83 | 0.88 | 0.031        | 0.033 | 0.035 |
| K1      | 0.35       | 0.40 | 0.45 | 0.014        | 0.016 | 0.018 |
| K2      | 0.34       | 0.39 | 0.44 | 0.013        | 0.015 | 0.017 |
| K3      | 0.30       | 0.35 | 0.40 | 0.012        | 0.014 | 0.016 |
| K4      | 0.23       | 0.28 | 0.33 | 0.009        | 0.011 | 0.013 |
| K5      | 0.33       | 0.38 | 0.43 | 0.013        | 0.015 | 0.017 |
| b       | 0.15       | 0.20 | 0.25 | 0.006        | 0.008 | 0.010 |
| b1      | 0.09       | 0.14 | 0.19 | 0.004        | 0.006 | 0.007 |
| e       | 0.45 BSC   |      |      | 0.018 BSC    |       |       |

### NOTE:

1. CONTROLLED DIMENSIONS ARE IN MILLIMETERS. DIMENSIONS IN INCHES ARE CONVERTED AS REFERENCE ONLY.

## Tape and Reel Dimensions, QFN5x5-36L

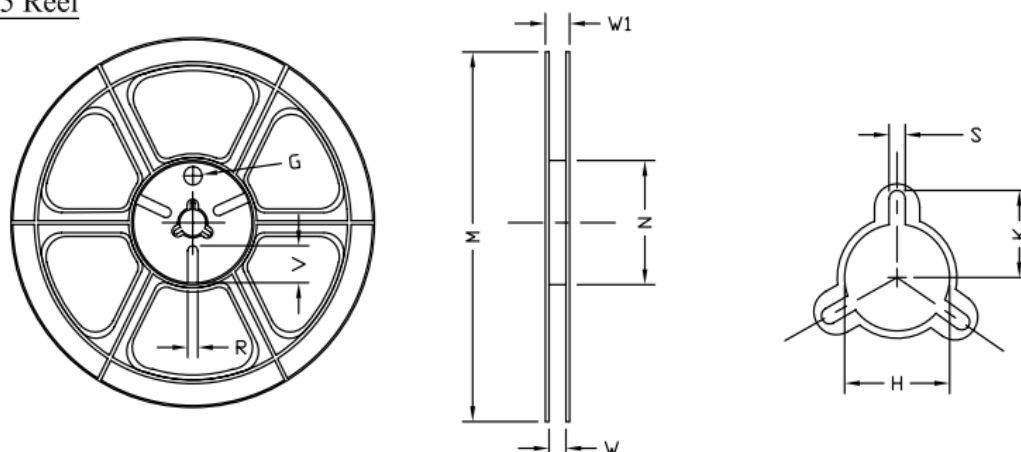
### QFN5x5 Carrier Tape



UNIT: MM

| PACKAGE           | A0            | B0            | K0            | D0           | D1                   | E            | E1            | E2            | P0            | P1            | P2            | T             |
|-------------------|---------------|---------------|---------------|--------------|----------------------|--------------|---------------|---------------|---------------|---------------|---------------|---------------|
| QFN5x5<br>(12 mm) | 5.25<br>±0.10 | 5.25<br>±0.10 | 1.10<br>±0.10 | 1.50<br>MIN. | 1.50<br>+0.1<br>-0.0 | 12.0<br>±0.3 | 1.75<br>±0.10 | 5.50<br>±0.05 | 8.00<br>±0.10 | 4.00<br>±0.10 | 2.00<br>±0.05 | 0.30<br>±0.05 |

### QFN5x5 Reel

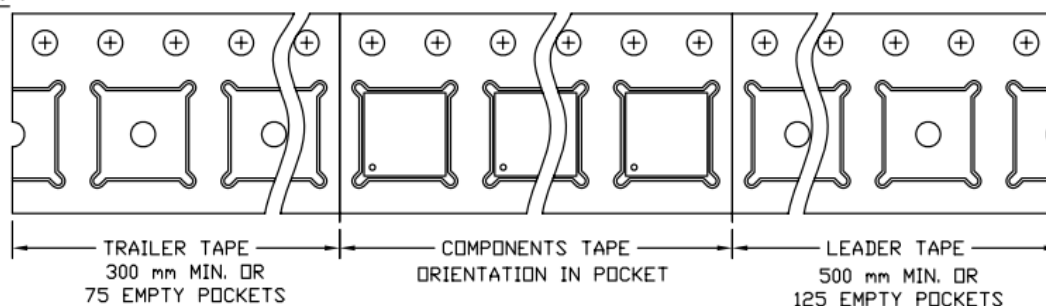


UNIT: MM

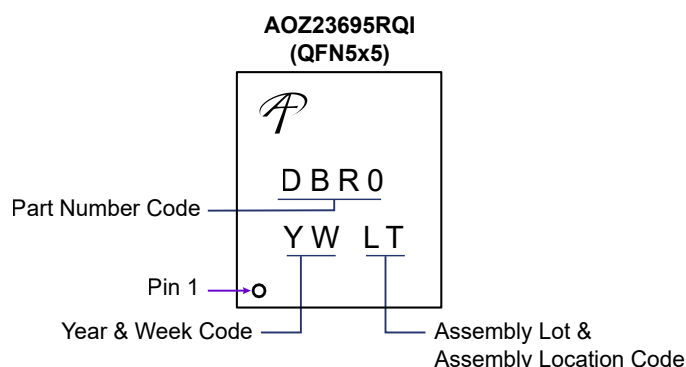
| TAPE SIZE | REEL SIZE | M              | N             | W                    | W1                   | H             | K            | S           | G   | R   | V   |
|-----------|-----------|----------------|---------------|----------------------|----------------------|---------------|--------------|-------------|-----|-----|-----|
| 12 mm     | ø330      | ø330.0<br>±2.0 | ø79.0<br>±1.0 | 12.4<br>+2.0<br>-0.0 | 17.0<br>+2.6<br>-1.2 | ø13.0<br>±0.5 | 10.5<br>±0.2 | 2.0<br>±0.5 | --- | --- | --- |

### QFN5x5 Tape

Leader / Trailer  
& Orientation



## Part Marking



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