Application examples of LDO regulators with high ripple rejection and fast load transient response

Description

LDO regulators with high ripple rejection ratio and fast load transient response are suitable for power supply circuits that require noise suppression, such as CMOS sensor power supplies and high-frequency circuits (RF blocks).
This application note uses our TCR5FM series, which features high ripple rejection and fast load transient response, as an example to explain application use cases, including various functions and characteristics. Please refer to this document when designing power circuits that require noise countermeasures.

Toshiba Electronic Devices & Storage Corporation

This is a reference material. Do not design the final equipment in this document.

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1. Introduction

LDO (Low Drop Out) regulators are a type of linear regulator that outputs a constant voltage lower than the input voltage. They can operate even with a small input-output voltage difference. They are widely used in various electronic devices, especially mobile devices such as smartphones and tablets, where a compact size, lightweight design, stable output voltage, and power efficiency are essential.

As high ripple rejection (R.R.) / power supply rejection ratio (PSRR) LDO, the TCR3RM, TCR5RG, and TCR5FM series are available in our lineup. This application note primarily focuses on the TCR5FM series.
The TCR5FM series achieves a ripple rejection ratio of 91 dB @ 1 kHz (typical) and features fast load transient response of -75 mV / -25 mV (typical) @ I_{OUT} = 0 mA ↔ 100 mA, 2.8 V output. It is available in fixed output voltage types ranging from 0.9 V to 5.0 V and supports a maximum output current of 500 mA (typical), making it suitable for a wide range of power supply applications. DFN4D packages (1.0 mm x 1.0 mm; t 0.37 mm typical) are also used, contributing to smaller and thinner sets.

For detailed information about the TCR5FM series, including its characteristics, please refer to the datasheet. For more information on the main characteristics of LDO regulators, please refer to the links below.

Downloading TCR5FM Series Data Sheets	→	Click Here
Downloading TCR3RM Series Data Sheets	→	Click Here
Downloading TCR5RM Series Data Sheets	→	Click Here
For basics of LDO	→	Click Here
For ripple rejection ratio	→	Click Here
For the load transient responses of LDOs	→	Click Here

2. Application Examples of LDO Regulators with High Ripple Rejection and Fast Load Transient Response

As shown in Figure 2.1, this document explains an application of LDO regulators with high ripple rejection and fast load transient response to RF blocks and CMOS sensors, using the TCR5FM series as an example.

Such design requirements have been increasing in recent years across a wide range of applications, including smartphones, wearable devices, and smart home appliances.

In power supplies used for RF blocks, weak high-frequency signals are handled, making power voltage fluctuations directly affect the signal. If the load transient response is slow, undershoot or overshoot in voltage may occur, potentially causing signal distortion or erroneous pulses during transmission. Additionally, in RF transmission devices, a slow load transient response can lead to unstable voltage during switching, causing issues such as frequency instability. Therefore, load transient response characteristics are particularly important. It is also crucial to minimize high-frequency noise that can interfere with RF signals. Accordingly, the required capability is to suppress switching noise from sources such as PMIC DC-DC converters and other high-frequency noise, which means high ripple rejection.

In case of CMOS sensors, instantaneous changes in current consumption occur during image readout and control signal switching. If the response is delayed, problems such as increased pixel noise and degraded image quality may arise. In addition, when high-frequency noise from the power supply is mixed into pixel signals, it appears in the image as random noise or fixed pattern noise. Therefore, as with RF blocks, fast load transient response and high ripple rejection are required.

The TCR5FM series of LDO regulators delivers high ripple rejection and fast load transient response with small package. The following sections explain specific circuit configurations.

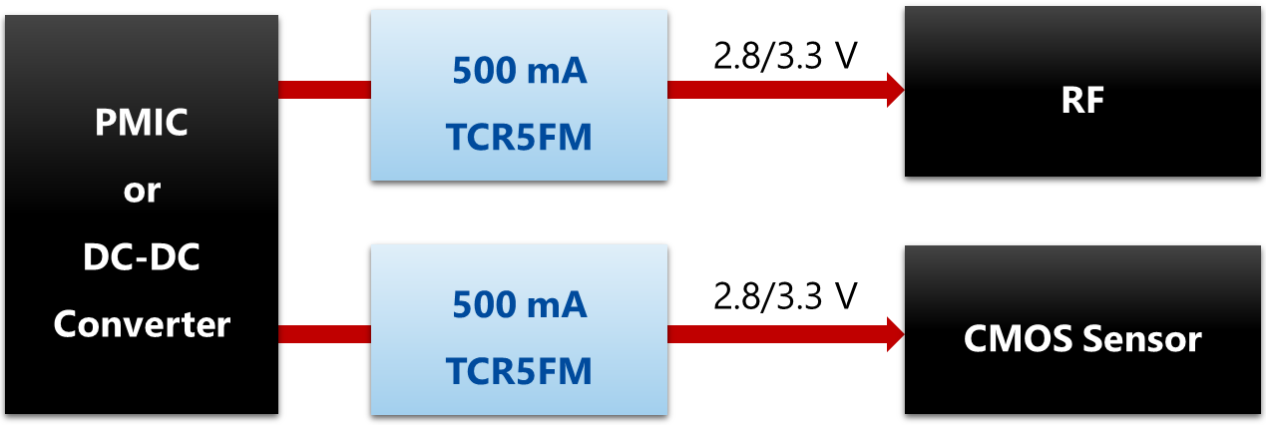
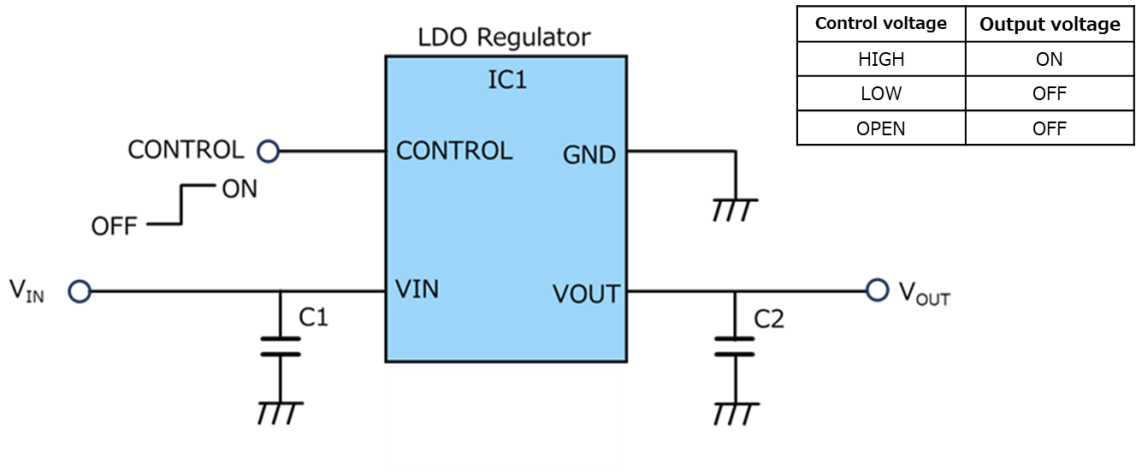


Figure 2.1 Application Examples of the TCR5FM Series

3. Application circuit

Figure 3.1 shows an example of an LDO regulator application circuit. Each capacitor is connected to the VIN and VOUT pins for stable operation (ceramic capacitors can be used).



Control voltage	Output voltage
HIGH	ON
LOW	OFF
OPEN	OFF

Figure 3.1 TCR5FM Series typical use case

4. Circuit and Board Design

4.1. Important Points for Design

This section explains the important points for designing circuits and boards using the TCR5FM series regulators.

- About External Capacitors

The capacitors have not only a feature to remove noise and ripple but also a significant impact on the performance of the power supply in terms of load response characteristics and oscillation. In addition, depending on the type of capacitor, they may have a large temperature characteristic. When selecting a capacitor, consider the operating environment thoroughly. For stable operation, 1.0 µF or more for the VIN pin and 1.0 µF or more for the VOUT pin capacitors are recommended.

- Mounting on Printed Circuit Board

External conditions, such as the pattern of the printed circuit board and the usage environment, can cause oscillation under the influence of wiring resistance and wiring inductance.

As a general precaution, the area of VIN, VOUT, and GND should be widened as much as possible to reduce wiring resistance. In addition, special attention should be paid to routing the path through which the input and output currents flow.

If the output capacitor is far from the VOUT pin, LDOs tend to be affected by impedance of the wiring resistance and the inductive component. For more stable power supply operation, the output capacitor should be mounted as close to the VOUT pin as possible (preferably at the base of the pin) which means it is separated from the routing of output current path and make sure that wiring impedance is not shared. If oscillation occurs unexpectedly, optimizing value and position of capacitor while measuring the output waveform with the board is recommended. Figure 4.1 shows an example of the evaluation board as described above.

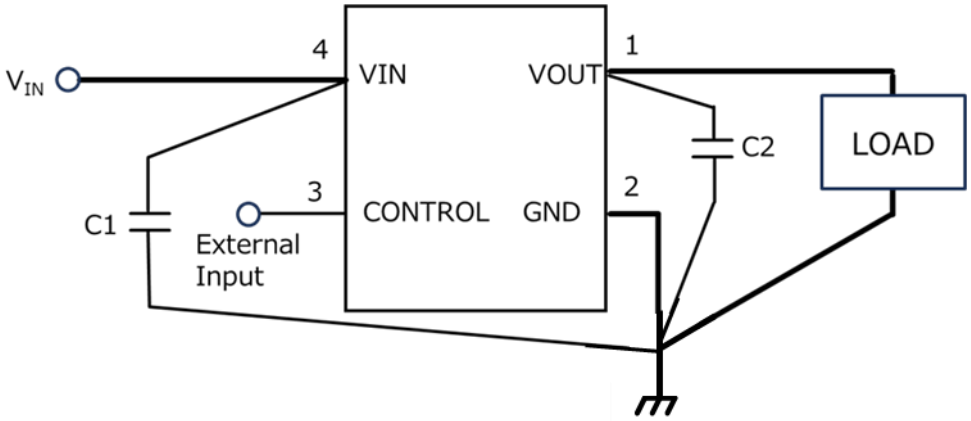


Figure 4.1 Example of Routing of Wiring Pattern

- Power Dissipation

  Design the board pattern with as much margin as possible for the maximum power dissipation based on actual use conditions. In addition, please consider parameters such as ambient temperature, input voltage, output current, etc., and consider an appropriate derating (generally 70% to 80% of the maximum value) for the maximum power dissipation.

- Overcurrent Protection Circuit and Thermal Shutdown Circuit

  The TCR5FM series has foldback type overcurrent protection circuit and thermal shutdown circuit, but these are not designed to constantly ensure the suppression of the device within its maximum rating.

  Depending on the condition during actual usage, it could affect the electrical characteristic specification and reliability. In addition, we do not guarantee that this product will not be destroyed under any circumstances. Also note that if VOUT pins and GND pins are not completely shorted out, these products might break down.

  When using the TCR5FM series, please refer to the absolute maximum ratings described above and in Toshiba's "Semiconductor Reliability Handbook" and in datasheets, and be careful not to exceed the absolute maximum ratings and take appropriate derating into consideration. Furthermore, Toshiba recommends inserting failsafe system into the design.

- Output Voltage V_{OUT} Rise Time

  The TCR5FM series has slew rate control function to reduce inrush current. The output rise time tends to be affected depending on the operating conditions, peripheral circuits, and ambient temperature, so please design with full consideration of your usage conditions.

- Bias Current Characteristics

  The bias current $I_{B(ON)}$ of the TCR5FM series is changed depending on the output current, I_{OUT}. If I_{OUT} is lower than threshold, TCR5FM series operates at low $I_{B(ON)}$, but in this state, the load transient response is inferior to normal state. The switching of $I_{B(ON)}$ by IOUT is controlled by hysteresis characteristics. When I_{OUT} increases and $I_{B(ON)}$ becomes larger, faster load transient response is expected. This characteristic is maintained until I_{OUT} becomes smaller and switches $I_{B(ON)}$ to low level.

4.2. Dropout Voltage: V_{DO}

The dropout voltage (minimum input-to-output voltage difference) is the minimum difference between the input voltage and the output voltage required for the LDO regulator to output a stable output voltage. The minimum input-to-output voltage difference for an LDO with a MOSFET in the output stage occurs when the MOSFET is operating in the linear region. The minimum input-to-output voltage difference then depends on the LDO regulator's on-resistance characteristics and the output current. The data sheet specifies this as the minimum difference between the input voltage and the output voltage required to output a given voltage. The lower this number, the lower the input voltage for which the desired output voltage can be obtained, and the lower will be the power consumption due to the loss caused by the voltage difference. It is important to note that if the voltage difference between the input and output is smaller than the dropout voltage, the expected output voltage cannot be obtained.

TCR5FM Series: 220 mV (typical) @2.8 V output, I_{OUT} = 500 mA

The dropout voltage to output current characteristics (reference values) of the TCR5FM series is shown below. Refer these when using these regulators.

TCR5FM Series

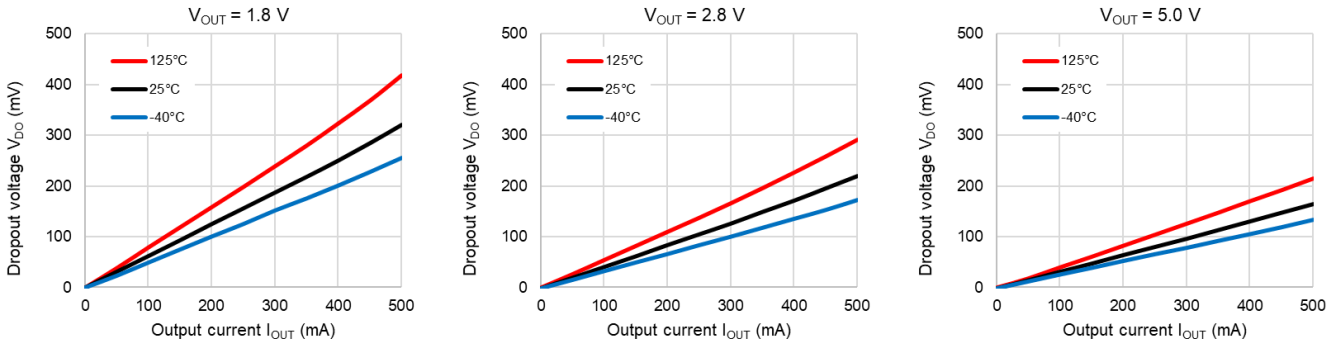


Figure 4.2 Dropout Voltage vs. Output Current of TCR5FM Series

4.3. Load Transient Response: ΔV_{OUT}

Load transient response characteristics refer to the amount of undershoot and overshoot that occur in the output voltage when the output current changes abruptly in a step-like manner.

LDO regulators with poor load response characteristics have a large fluctuation in the output voltage when the output current changes abruptly and then take a long time to return to the normal output voltage, which has an impact on risk of affecting the downstream ICs or circuits connected to the output of LDOs. The size of the load connected to the output of the LDO regulator is not constant, so the output current also fluctuates accordingly. However, the TCR5FM series has excellent response performance to sudden current changes and maintains stable constant-voltage operation. It also has excellent load transient response in both loaded and unloaded conditions. At a 2.8 V output, the load transient from 1 mA to 500 mA is -60 mV/+40 mV typical, and from 0 mA to 100 mA is -75 mV/+25 mV typical.

The load transient response characteristics of the TCR5FM series regulators are shown below (reference values). Refer to these when using these regulators.

TCR5FM Series

Measurement conditions
@C_{IN} = 1.0 µF, C_{OUT} = 1.0 µF,
V_{IN} = 3.3 V (V_{OUT} = 2.8 V),
t_r = 1.0 µs, t_f = 1.0 µs, I_{OUT} = 1 mA ↔ 500 mA or 0 mA ↔ 100 mA, T_a = 25°C

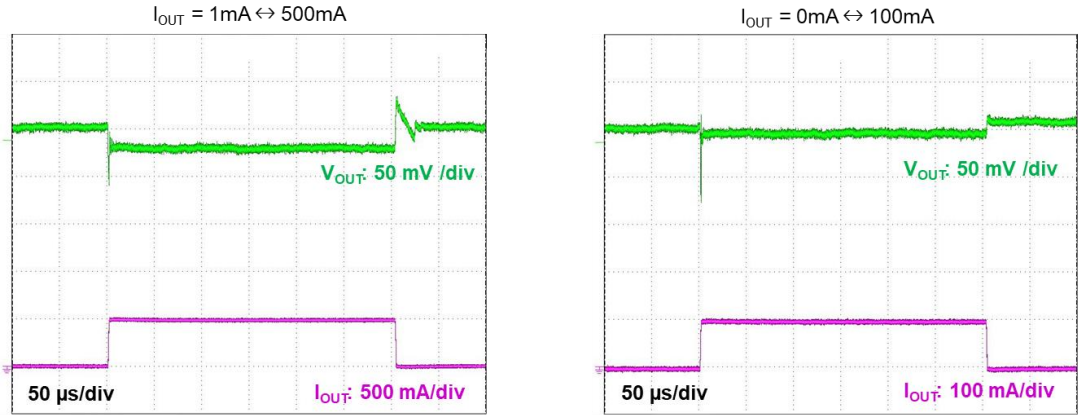


Figure 4.3 TCR5FM Series Load Transient Response

4.4. Ripple Rejection Ratio: R.R., PSRR (Power Supply Rejection Ratio)

R.R. (PSRR) indicates the ratio of the ripple voltage rejection on the input voltage and output voltage at that time. The higher value means, the smaller ripple appears on the output. Sometimes it may be indicated as negative by swapping the denominator and numerator, in which case the smaller is better.

R.R. is given by the following equation. R.R. has a frequency dependency, and if a switching regulator is connected before the LDO regulator, the higher the R.R. value, the more ripple on the input voltage can be removed. This serves as an indicator when using LDO for power supplies for noise sensitive sensor circuits and analog circuits.

$$R.R. = 20 \times Log \frac{V_{IN\ ripple}}{V_{OUT\ ripple}} \quad (dB)$$

$V_{IN\ ripple}$: ripple voltage (V) of input voltage V_{IN}
$V_{OUT\ ripple}$: ripple voltage (V) of output voltage V_{OUT}

The TCR5FM series features high-frequency ripple rejection ratio, with typical values of 67 dB@100 kHz and 59 dB@1 MHz. The ripple rejection ratio vs. frequency characteristics of the TCR5FM series is shown below (reference values). The characteristic curve is shown when there is no external capacitance C_{IN} and C_{OUT} is 1.0 µF. Refer to these when using these regulators.

TCR5FM Series

Measurement conditions
@C_{IN} = none, C_{OUT} = 1.0 µF, V_{IN} = 2.0 V (V_{OUT} = 0.9 V) or 2.3 V (V_{OUT} = 1.8 V) or 3.3 V (V_{OUT} = 2.8 V) or 5.5 V (V_{OUT} = 5.0 V),
$V_{IN\ Ripple}$ = 200 mV_{p-p}, I_{OUT} = 10 mA, T_a = 25°C

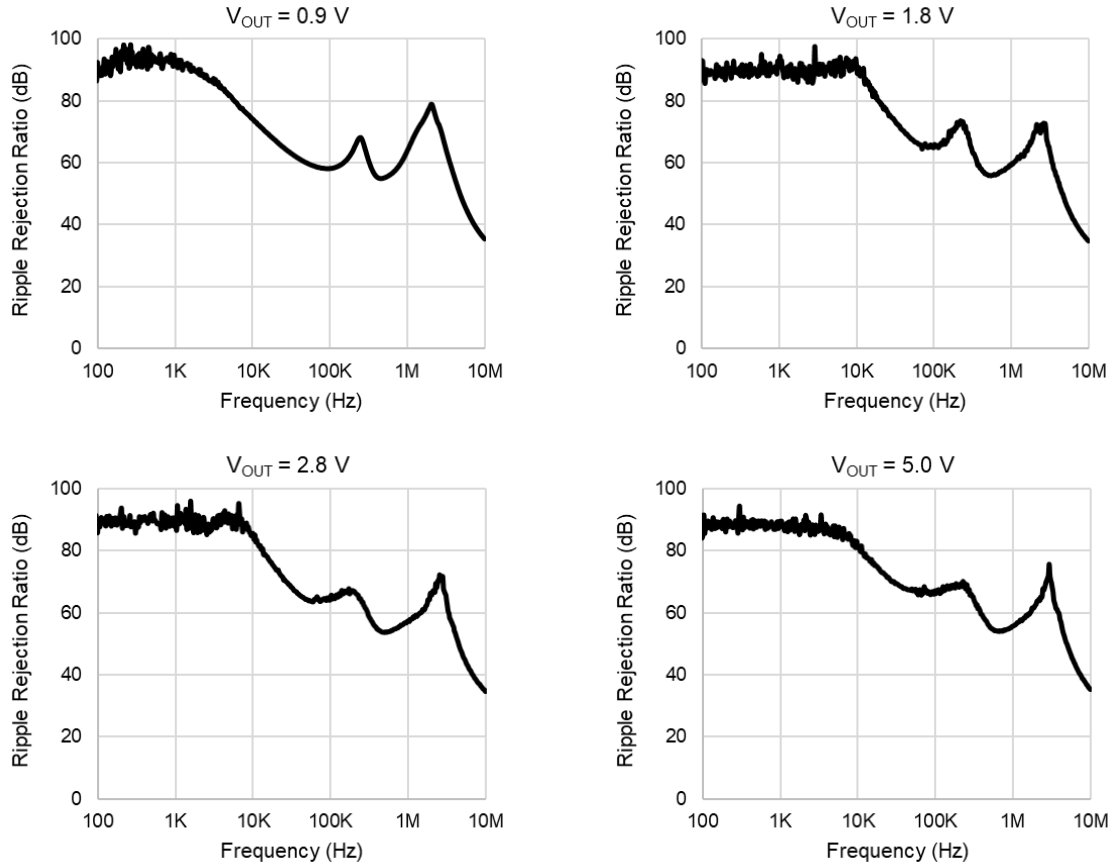


Figure 4.4 Ripple Rejection Ratio vs. Frequency Response of TCR5FM Series

4.5. Internal Circuits and Functions

TCR5FM series regulators include the following circuits and functions:

- Overcurrent Protection Circuit

If the output current exceeds the current limit due to a load abnormality or a short circuit, the output voltage will begin to decrease and the output current will also decrease, thereby reducing the power consumption during the abnormality. This protection operation is referred to as “current limit foldback." When V_{OUT} has dropped to zero, it keeps the output current at a limited constant level. When the overcurrent condition has disappeared, V_{OUT} returns to the normal level automatically.

- Thermal Shutdown Circuit

If the temperature of the LDO regulator exceeds the set value because of the continuous flow of a large current due to a short circuit at the load, a protective action is performed to turn off the output to prevent degradation or destruction of the LDO regulator.

- Inrush Current Suppression Loop (Slew Rate Control Function)

When the output is turned on, a charging current flows to the output capacitor, but if this current is too large, the overcurrent protection circuit may work unexpectedly and the start-up may fail, or the output voltage may be overshoot. To prevent this, this is the function to reduce inrush current by getting the output voltage slowly increase.

- Auto Discharge Function

This function discharges the residual charge of the output capacitor when the output is turned off by CONTROL pin.

5. Product Overview

The TCR5FM series LDO regulators feature output currents of up to 500 mA and are available in the ultra-small DFN4D (1.0 mm x 1.0 mm; t 0.37 mm (typical)) package. With an output voltage range of 0.9 V to 5.0 V, it is ideal for applications that require high-density mounting, such as mobile devices.

In addition, each series has a built-in overcurrent protection circuit, thermal shutdown circuit, inrush current suppression circuit (slew rate control function), and auto-discharge function. Please refer to the data sheet for details of the TCR5FM series.

Key features of the TCR5FM series include:

Features

- Wide range output voltage lineup (V_{OUT} = 0.9 to 5.0 V)
- Low dropout voltage

V_{DO} = 160 mV (typical) @5.0 V output, I_{OUT} = 500 mA
V_{DO} = 220 mV (typical) @2.8 V output, I_{OUT} = 500 mA
V_{DO} = 340 mV (typical) @1.8 V output, I_{OUT} = 500 mA

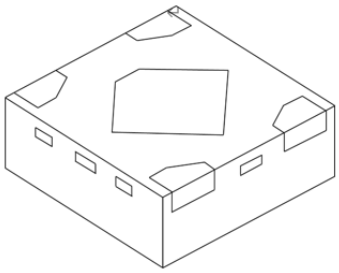
- Low output noise voltage (V_{NO} = 5 μV_{rms} (typical) @10 Hz ≤ f ≤ 100 kHz)
- High ripple rejection ratio (91 dB (typical) @1 kHz, 89 dB (typical) @10 kHz, 67 dB (typical) @100 kHz, 59 dB (typical) @1 MHz, 2.8 V output, I_{OUT} = 10 mA)
- Fast load transient response

(-60 mV / +40 mV (typical) @2.8 V output, I_{OUT} = 1 mA ↔ 500 mA
-75 mV / +25 mV (typical) @2.8 V output, I_{OUT} = 0 mA ↔ 100 mA)

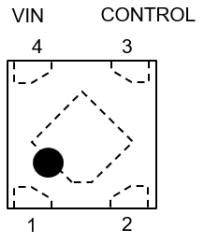
- Overcurrent protection
- Thermal shutdown
- Auto-discharge
- Pull down connection between CONTROL and GND
- Ceramic capacitors can be used (C_{IN} = 1.0 µF, C_{OUT} = 1.0 µF)

Appearance and Pin Arrangement

Appearance of the DFN4D Package



Pin Arrangement (Top view)



Note: Center electrode should be connected to GND or Open

Figure 5.1 Appearance and Pin Arrangement of TCR5FM Series

Table 5.1 Pin Description of TCR5FM Series

Pin number	Pin name	Pin Description
1	VOUT	Output pin
2	GND	Ground pin
3	CONTROL	Output ON/OFF control pin
4	VIN	Power supply input pin

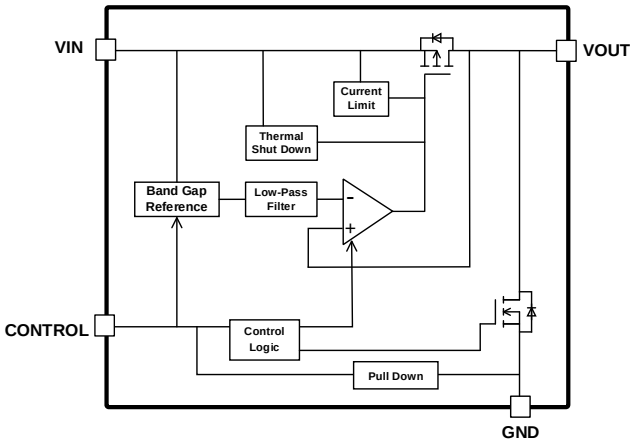


Figure 5.2 Internal Circuit Block Diagram of TCR5FM Series

6. Related Links

The TCR5FM series features high ripple rejection and fast load transient response, which is suitable for power supplies in cameras, IoT devices, sensors, and RF modules. In addition, Toshiba also offers other high ripple rejection LDO products such as the TCR3RM series and the TCR5RG series. For related applications, datasheets, and web pages, please refer to the links below.

Related Applications

Consumer/Personal: Smart Plug, Smart Speaker, IoT Sensor, Smart Watch, Wireless Earbuds, Action Camera, Tablet Device, Wireless Charger, Solid State Drive
Industrial: Serveillance Camera, Human Sensor

Related Datasheets

LDOs with High Ripple Rejection

TCR5FM Series (500 mA/DFN4D/Fast Load Transient) datasheet → Click Here

TCR3RM Series (300 mA/DFN4D) datasheet → Click Here

TCR5RG Series (500 mA/WCSP4F) datasheet → Click Here

Related Web Pages

■Product Line Ups (Catalog) Click

■Product Line Ups (Detail) Click

■Product Line Ups (Parametric search) Click

■Stock check & Purchase Buy Online

■FAQ of Low Dropout Regulator ICs Click

■Application Notes Click

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