

# LDO Regulator ICs Enhancing Sophistication of Mobile Devices

With the expansion of the mobile phone market in recent years, global annual shipments of mobile phone products will exceed 1.8 billion units in fiscal 2017. Smartphones have become an indispensable part of daily life due to their advanced functionality that cannot be realized with conventional feature phones.

To enhance the functionality of mobile devices typified by smartphones, Toshiba Electronic Devices & Storage Corporation is promoting the development of discrete semiconductor products, including low-dropout (LDO) regulator integrated circuits (ICs), featuring superior power supply ripple rejection characteristics and load transient response as well as low power consumption.

## 1. Introduction

With the growth of the mobile phone market, annual shipments will exceed 1.8 billion units in fiscal 2017. As the typical mobile devices of today, smartphones have become familiar tools indispensable for daily life, and their driving force is the rapid advances in functionality that are impossible to attain with feature phones. Demand for semiconductors having advanced functions that cannot be realized by the main system on a chip (SoC) or power management IC has increased with the arrival of high-function, high-added-value mobile devices being developed worldwide.

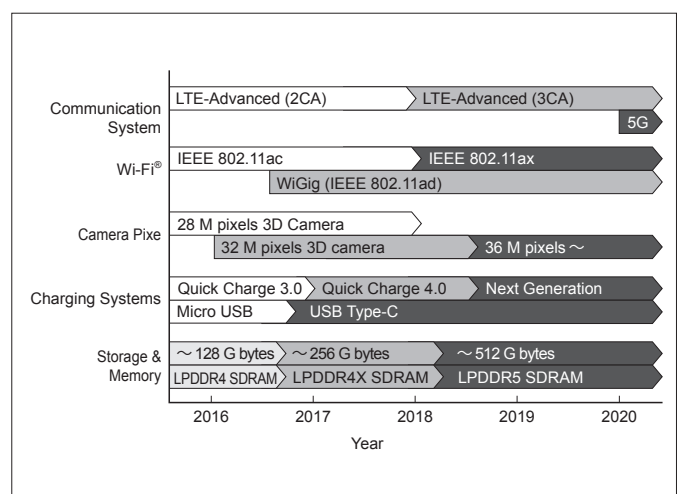
Toshiba Electronic Devices & Storage Corporation has developed discrete semiconductor products that respond to these technology trends, contributing to the advancement of the mobile market. Here, we describe the LDO regulator, which is one of the power supply ICs.

## 2. Sophistication of mobile devices

First, the system trends of mobile devices are shown in Figure 1.

For the communication system, Long Term Evolution (LTE)-Advanced is becoming widespread, enabling high-speed communications at much higher capacity than conventional third generation (3G). Also, ultra-high-speed communication techniques such as carrier aggregation (CA) that combines multiple frequencies to multiplex data, and the commercial introduction of 5G (fifth generation) communications in 2020, will further accelerate this trend.

In addition to LTE, high-speed data communication



(Figure 1) : Trends in mobile devices from perspective of advances in functionality

using frequencies above 2 GHz (exemplified by Wi-Fi®) is an important communications method. Using the International Electrical and Electronic Engineers (IEEE) 802.11ac standard, high-speed communication of 6.9 Gbit/sec has been realized using the 5 GHz band, and in 2019, an even higher 10 Gbit/sec will be achieved using the next IEEE 802.11ax standard.

In addition to advances in communications protocols, image sensors inside mobile cameras have been undergoing improvement to increase the pixel count and data throughput. 3D (stereoscopic) cameras equipped with multiple image sensors have been developed starting from high-end models and subsequently expanding to middle-range and eventually to low-end models.

Other notable advances include the introduction of the Universal Serial Bus (USB) Type-C with its quick-charging capability to cater to ever-growing battery capacity. In addition, 3-dimensional (stacked) flash memories for storage, low power double data rate (LPDDR) synchronous DRAM (SDRAM) for main memory increases capacity and data transfer rates.

### 3. Trend of mobile power devices

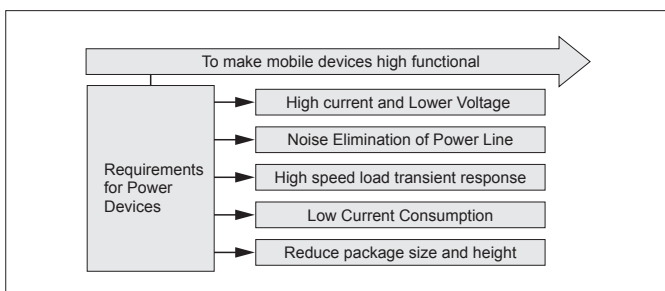
All of the functional improvements described in Chapter 2 are technologies with clear benefits, but the main challenge is to deal with the constraints of mobile devices. For example, mobile devices are required to operate as long as possible with limited battery capacity. As one way to alleviate this problem, increasing the battery capacity and reducing the charging time by increasing the current flow are being addressed. In addition, a lower operating voltage of the system IC (1V or less) and a larger current capacity of the power supply device will be required.

With the reduction in voltage and increase in current, power supply devices are required to have the characteristics shown in Figure 2. There is a pressing need for high-quality, compact power supply devices.

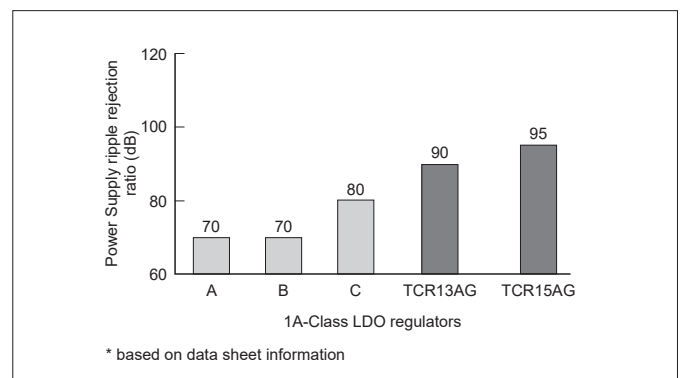
In response to these demands, we have achieved the world's smallest<sup>(\*1)</sup> LDO regulators, (the TCR15AG, with an output current of 1.5 A, the TCR13AG with an output current of 1.3 A, and the TCR3UG with a low current consumption of 0.34 μA) —all having excellent noise removal performance and load transient response while minimizing power consumption. In addition, other attributes emphasized in our design of these LDO regulators include absorbing static electricity accumulating on the power supply line and signal line, enhancing protection by means of an electrostatic discharge (ESD) protection diode, and contributing to the high functionality of mobile devices.

#### 3.1 Performance of power supply line noise removal

Since mobile devices are normally used while being carried around, in order to efficiently use the limited battery capacity, the battery is generally connected to a switching power source operating as a DC-DC converter.



(Figure 2) : Characteristics of power supply device requirements for mobile devices



(Figure 3) : Comparison of Supply Ripple rejection characteristics of LDO regulators of 1-A class

(\*1) I For LDO regulator ICs with an output current of 1.5 A, based on a survey conducted by Toshiba Electronic Devices & Storage Corporation in September 2017.

Although this switching power supply can convert voltages efficiently, since power conversion is accomplished by repeating the on/off operation, switching noise is generated and superimposed on the output voltage waveform. Noise from the power source is inimical to the good performance of image sensors, RF (high frequency) power amplifiers, audio amplifiers, etc. since it would degrade the image quality and communication quality. Therefore, an LDO regulator operating in the linear region is placed between the switching power supply and the sensor or amplifier to remove this noise. In general, the noise removal performance of an LDO regulator having an output current of 1 A or more is about 70 dB for a 1 kHz noise.

In the case of our TCR15AG, we blocked the noise path leaking from the power supply to inside the circuit as much as possible through improvement of open loop gain and layout routing. As a result, the industry's highest<sup>(\*\*1)</sup> noise removal capability of up to 95 dB has been achieved, meaning a 20-fold improvement in noise removal capability compared with comparable LDO regulators (Figure 3).

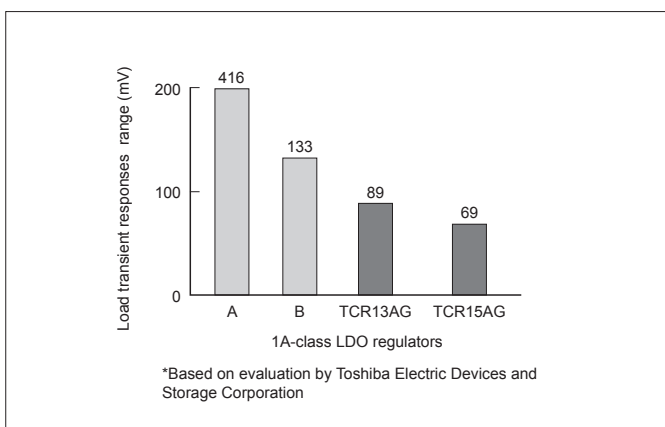
### 3.2 High-Speed Load Transient Response Characteristics

The load current of the LDO regulator is the current consumed by the connected sensors or amplifiers, and it can fluctuate greatly. For example, when the image sensor changes from a dark subject to a bright subject, the current consumption rapidly increases. In addition, the slow motion video recording function often found on recent smartphones has been realized by setting the frame rate to, for example, 30 times normal, and the current consumption increases. Furthermore, as the number of pixels increases, the maximum current also increases.

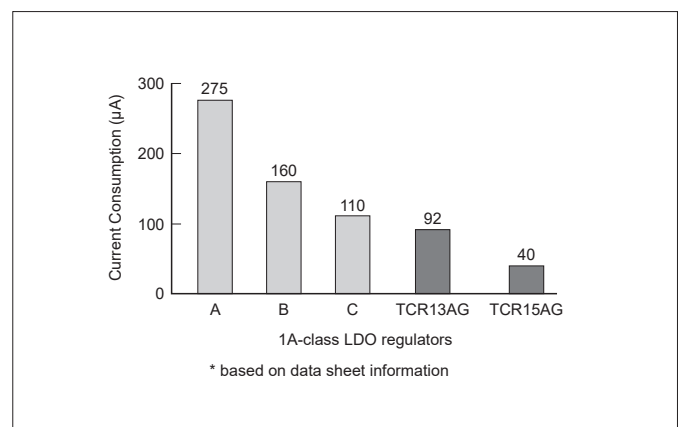
Indicative of how much the transient voltage fluctuation of the output can be suppressed when the load current suddenly changes and how quickly it can be returned to the steady state is the load transient response, where there is demand for improved performance. Although this characteristic greatly depends on the previous-stage drive capability of the output transistor, we can achieve fast responses and a voltage fluctuation less than 1/2 that of general LDO regulators by securing sufficient previous-stage drive capability (Figure 4).

### 3.3 Low current consumption characteristics

The current consumption of the LDO regulator itself is normally several tens of  $\mu\text{A}$  to several hundreds of  $\mu\text{A}$ . In mobile devices, image sensors (camera functions) and RF power amplifiers (for wireless functions such as Wi-Fi<sup>®</sup> and Bluetooth<sup>®</sup>) are not operating at all times, and are usually in standby states. Since there is no current consumption in the sensor or the amplifier during standby, the current consumption of the LDO regulator itself affects the long-term operation of the mobile device, that is, the "life" of the battery.



(Figure 4) : Comparison of load transient responses of 1A-class LDO regulators



(Figure 5) : Comparison of no-load current consumption of 1A-class LDO regulators

In general, when current consumption is reduced, the noise removal performance of the power supply line and the high-speed load transient response deteriorate, and therefore there is a trade-off.

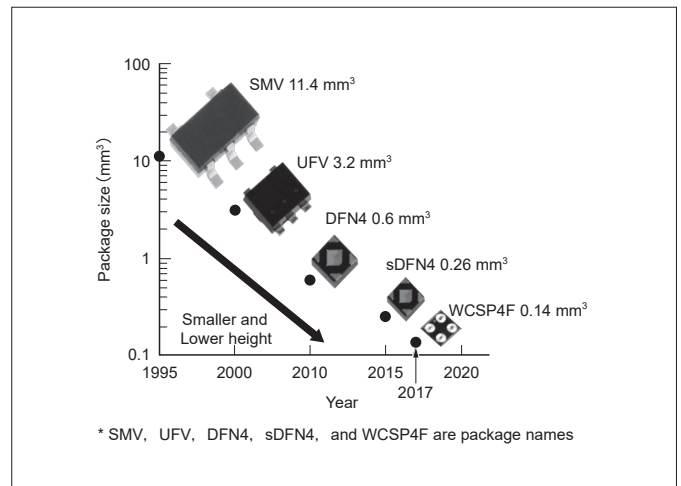
Our company achieves excellent noise removal characteristics and load transient response characteristics while securing adequate drive current when there is a load and automatically reduces the drive current to suppress the current consumption when there is no load. As a result, a low current consumption about 1/2 that of comparable LDO regulators is realized (Figure 5).

### 3.4 Compact and low-height packaging for high-density assembly

Along with the increase in battery capacity and the thinning of mobile devices themselves, miniaturization and low-height packages are progressing rapidly to achieve high-density mounting of electronic components within a limited board space (Figure 6).

In the 1990s, small LDO regulators for mobile use were mainly encased in 2.9 x 2.8 x 1.4 mm (width x length x height) packages. Since around 2010, leadless packages of 1.0 x 1.0 x 0.65 mm (width x length x height) have become mainstream.

In response to this demand for miniaturization, we are developing a WCSP4F package with dimensions of 0.645 x 0.645 x 0.33 mm (width x length x height), which is one of the world's smallest in class<sup>(\*1)</sup>.



(Figure 6) : Trends in LDO regulator packages for mobile devices

## 4. Conclusion

We have focused on the high-performance LDO regulator required for realizing advanced mobile functions, highlighting the use of our company's component technology.

We will continue to develop optimal discrete semiconductors that meet the trends of the mobile market and contribute to the advancement of mobile devices.

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