

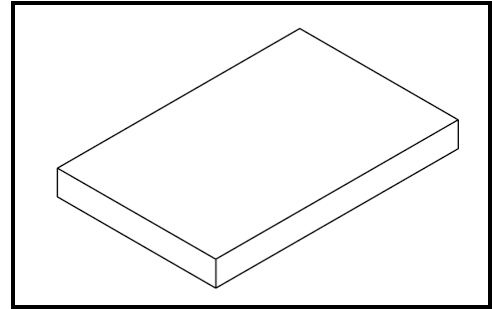
TOSHIBA CDMOS Integrated Silicon Monolithic Circuit

TC7765WBG

Wireless Power Receiver Controller IC

1. Outline

The TC7765WBG is wireless power receiver (RX) IC using communication protocol of wireless power consortium (WPC). The TC7765WBG has a rectifier circuit, a digital control circuit, a modulation circuit for communication which controls the supply voltage to the load. The IC includes all RX functions needed to construct a standalone wireless power system. The TC7765WBG can build a wireless power system by combining it with Exclusive version of TB6865AFG.



S-XFLGA28-0304-0.50-001

2. Applications

Mobile communication devices (Smartphone, Tablet, Wearable), battery pack, mobile accessory etc.

3. Features

- Full bridge rectifier circuit
 - Auto switch for 3 modes : Synchronous rectification / Diode rectification / Diode bridge
 - Low ON resistance : High Side 45 mΩ (Typ.) / Low side 30 mΩ (Typ.)
 - Under Voltage Lockout (UVLO) / Over Voltage Detection (OVP) function
- Output voltage : 10 V (Max)
- Maximum output current : 1.0 A
- Over Current Protector (OCP) : 1.3 A
- Foreign Object Detection (FOD) function
- Under voltage lockout (UVLO) / Over voltage detection (OVLO) function
- Thermal shutdown function (TSD)
- Package : S-XFLGA28-0304-0.50-001 (2.40 mm*3.67 mm*0.5 mm, 0.5 mm pitch)

Please use this product in combination with exclusive version of TB6865AFG.
This wireless power system incorporates a foreign object (exp. metal pieces) detection function, but a foreign object may generate heat in time before detecting it. About the foreign object, please be careful enough.

This product has a MOS structure and is sensitive to electrostatic discharge. When handling this product, ensure that the environment is protected against electrostatic discharge by using an earth strap, a conductive mat and an ionizer. Ensure also that the ambient temperature and relative humidity are maintained at reasonable levels.

4. Block diagram

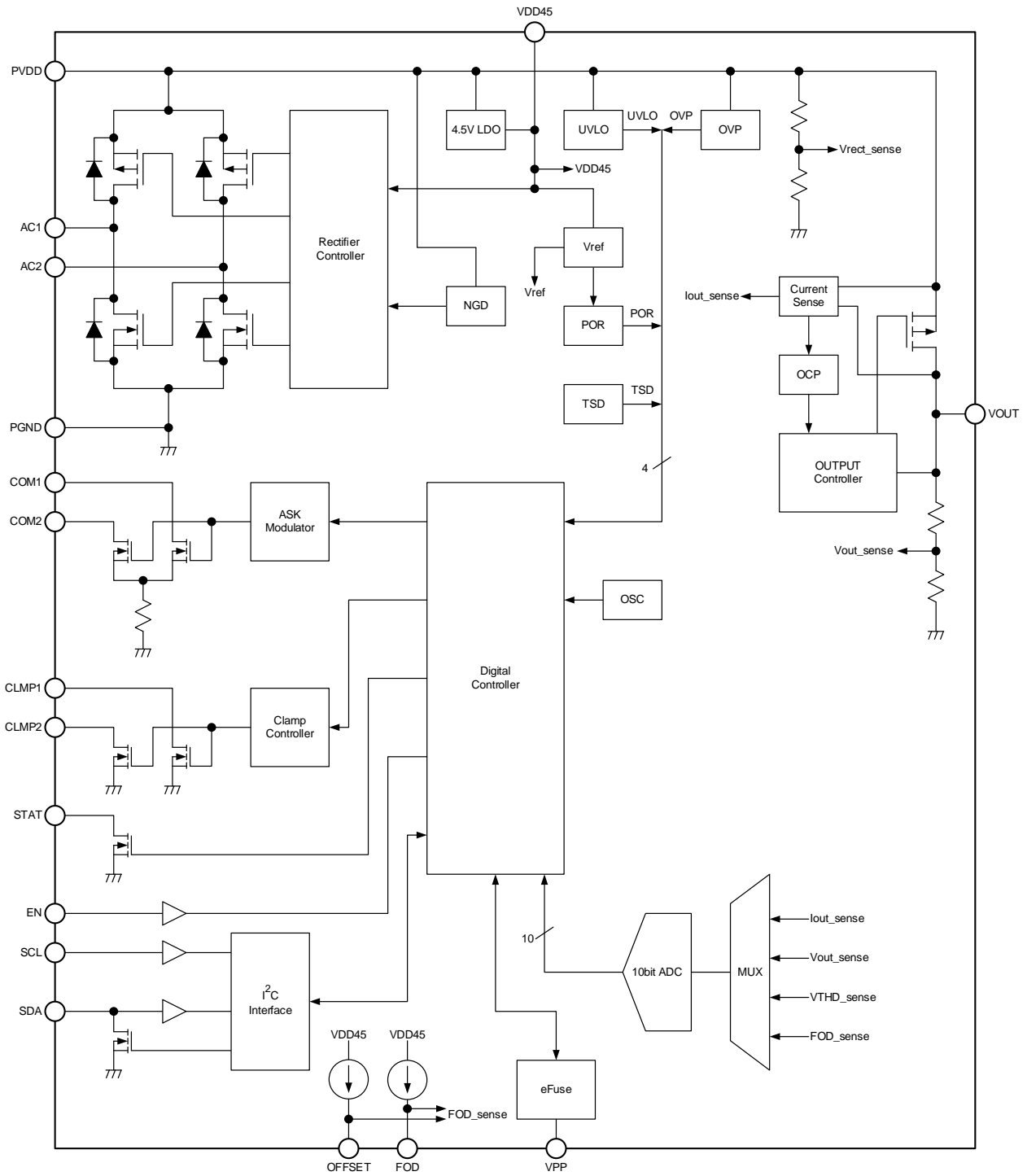


Figure 4.1 Block diagram

5. Pin assignment

| | 1 | 2 | 3 | 4 |
|---|-------|------|-------|--------|
| A | PGND | PGND | PGND | PGND |
| B | AC2 | AC2 | AC1 | AC1 |
| C | CLMP2 | PVDD | PVDD | CLMP1 |
| D | VOUT | VOUT | VOUT | VOUT |
| E | COM2 | SDA | SCL | COM1 |
| F | VDD45 | VPP | TEST1 | TEST2 |
| G | FOD | EN | STAT | OFFSET |

(Top View)

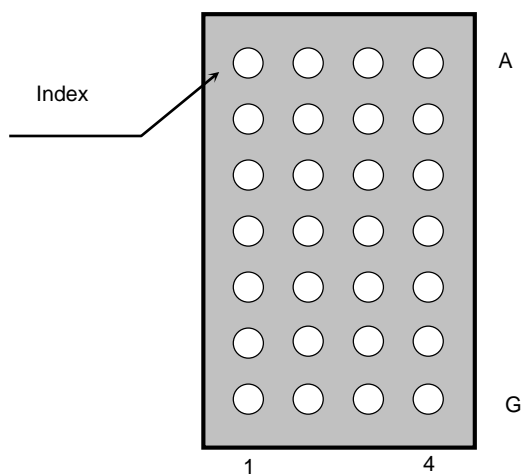


Figure 5.1 Ball assignment (Top View)

6. Pin function

Table 6.1 Pin function

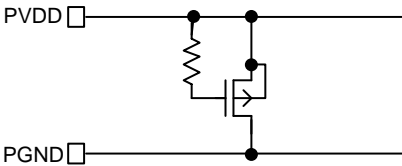
| Pin Number | Pin symbol | I/O | Description |
|------------------|------------|-----|---|
| A1, A2 A3, A4 | PGND | - | Power ground Connect to common ground (GND). |
| B1, B2 | AC2 | I | Antenna terminals for receiver 2 |
| B3, B4 | AC1 | I | Antenna terminals for receiver 1 |
| C1 | CLMP2 | O | Clamp terminal for over voltage protection 2 Open drain terminal. Please connect a condenser of 0.47 μ F to AC2 when use an internal clamping circuit. |
| C2, C3 | PVDD | - | Rectifier output and power supply terminal Output of bridge rectifier circuit and IC power supply terminal. Connect smoothing capacitor. And connect zener diodes between PVDD and PGND when use an internal clamping circuit. |
| C4 | CLMP1 | O | Clamp terminal for over voltage protection 1 Open drain terminal. Please connect a condenser of 0.47 μ F to AC1 when use an internal clamping circuit. |
| D1, D2 D3, D4 | VOUT | O | Output terminals Connect capacitor of more than 1.0 μ F to GND. |
| E1 | COM2 | O | Capacitor connect for ASK modulation 2 Open drain terminal. Connect capacitor to AC2. |
| E2 | SDA | I/O | I ² C data I/O terminal for Toshiba tests Connect to GND. |
| E3 | SCL | I | I ² C clock input terminal for Toshiba tests Connect to GND. |
| E4 | COM1 | O | Capacitor connect for ASK modulation 3 Open drain terminal. Connect capacitor to AC2. |
| F1 | VDD45 | O | 4.5 V- LDO output terminal 4.5 V- LDO output terminal for internal circuit. Connect capacitor of more than 0.1 μ F to GND. |
| F2 | VPP | I | eFuse writing terminal Short to VDD45 in normal use. |
| F3 | TEST1 | O | Make this terminal open. |
| F4 | TEST2 | I | Connect to GND |
| G1 | FOD | I | Offset terminal for RX loss adjustments. Loss offset terminal for FOD Connect appropriate resistor to GND. |
| G2 | EN | I | Wireless charging enable input terminal with internal pull-up resistor. When the terminal is "H" or "Open", TC7765WBG is ready for wireless charging. When the terminal is "L". TC7765WBG wireless power receiver is disabled. |
| G3 | STAT | O | Status output terminal Open drain terminal. Connect pull-up resistor. |
| G4 | OFFSET | I | Offset terminal for RX loss adjustments Loss offset terminal for FOD. Connect appropriate resistor to GND. |

7. Equivalent circuits for input/output/power supply terminals

7.1 Power supply terminal

Table 7.1 Equivalent circuits for power supply terminals

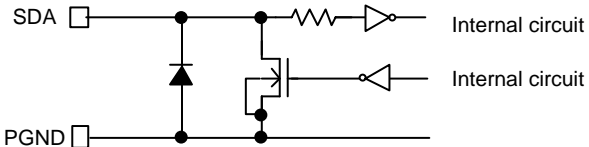
Note: Equivalent circuits may be simplified to illustrate circuits.

| Pin name | Equivalent circuit |
|----------|---|
| PVDD |  <p>The diagram shows the equivalent circuit for the PVDD terminal. It consists of a resistor connected between the PVDD pin and the gate of a PMOS transistor. The source of the PMOS transistor is connected to PGND, and its drain is connected to the PVDD pin. This configuration represents the internal pull-up structure of the power supply terminal.</p> |

7.2 Input/output terminal

Table 7.2 Equivalent circuits for Input/output terminals

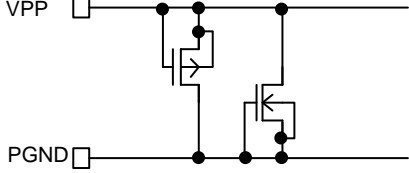
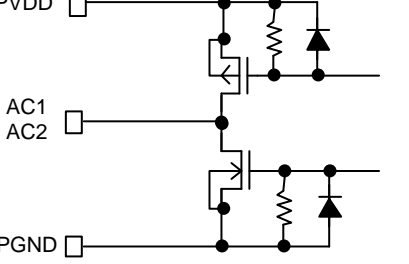
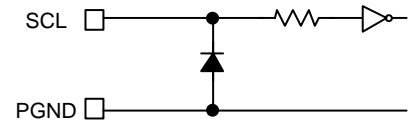
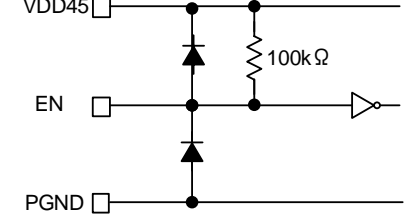
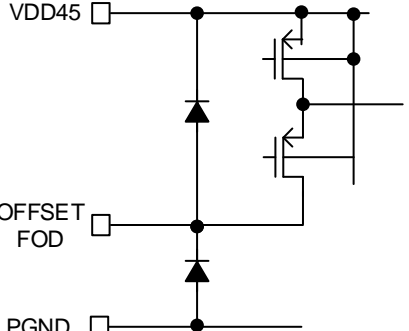
Note: Equivalent circuits may be simplified to illustrate circuits.

| Pin name | Equivalent circuit |
|----------|--|
| SDA |  <p>The diagram shows the equivalent circuit for the SDA terminal. It includes a pull-up resistor connected to the SDA pin. A diode is connected between the SDA pin and PGND, with the anode at the SDA pin. The circuit also shows internal circuitry, including a PMOS transistor and an internal circuit block, connected to the SDA pin and PGND.</p> |

7.3 Input terminal

Table 7.3 Equivalent circuits for input terminals

Note: Equivalent circuits may be simplified to illustrate circuits.

| Pin name | Equivalent circuit |
|---------------|---|
| VPP |  |
| AC1 AC2 |  <p style="text-align: right;">Internal circuit</p> <p style="text-align: right;">Internal circuit</p> |
| SCL |  <p style="text-align: right;">Internal circuit</p> |
| EN |  <p style="text-align: right;">Internal circuit</p> |
| OFFSET FOD |  <p style="text-align: right;">Internal circuit</p> |

7.4 Output terminal

Table 7.4 Equivalent circuits for output terminals

Note: Equivalent circuits may be simplified to illustrate circuits.

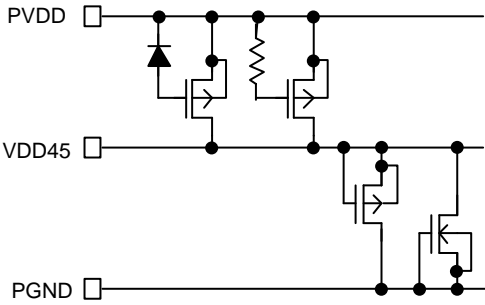
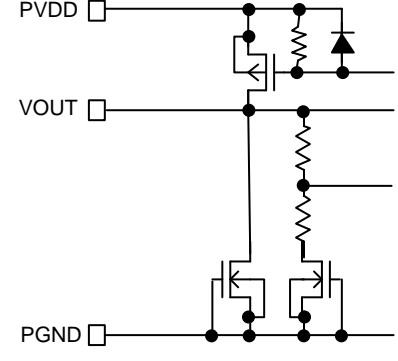
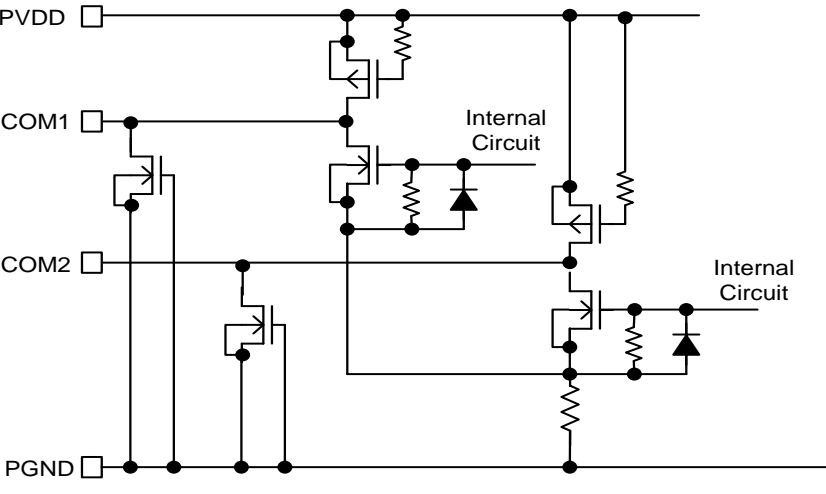
| Pin name | Equivalent circuit |
|--------------|--|
| VDD45 |  |
| VOUT |  |
| COM1 COM2 |  |

Table 7.5 Equivalent circuits for output terminals

Note: Equivalent circuits may be simplified to illustrate circuits.

| Pin name | Equivalent circuit |
|----------------|---|
| CLMP1 CLMP2 | <p>PVDD □</p> <p>CLMP1 □</p> <p>CLMP2 □</p> <p>PGND □</p> <p>Internal circuit</p> |
| STAT | <p>STAT □</p> <p>PGND □</p> <p>Internal circuit</p> <p>Internal circuit</p> |

8. Functions / Operation description

8.1 General outline of wireless power system

Wireless power system consists of the first side (TX) which transmits power and the second side (RX) which receives power. Power is transmitted by adjoining coils included in the TX and RX and by sharing and combining their electromagnetic flux. The RX controls the transferred power by monitoring the received power and sending feedback signals to the TX. The TX controls the power by controlling its transmitted power according to the feedback signal which is received from the RX. A configuration example of a wireless power system is shown in Figure 8.1.

Communication signals from RX to TX are transmitted (modulated) by ASK modulation. The communication rate and its packets are defined by the Qi standard. Communication rate is 2 kbps. Packets are ID, identification signal, error information, receive power, and stop signal. The TX is powered on intermittently and confirms the existence of a RX on the TX pad. When the TX recognizes a RX it succeeds to the identification phase; transmit operation starts after a compliant RX has been identified. The TX continues the transmit operation until it cannot recognize the existence of a RX or receives a transmit stop signal from the RX.

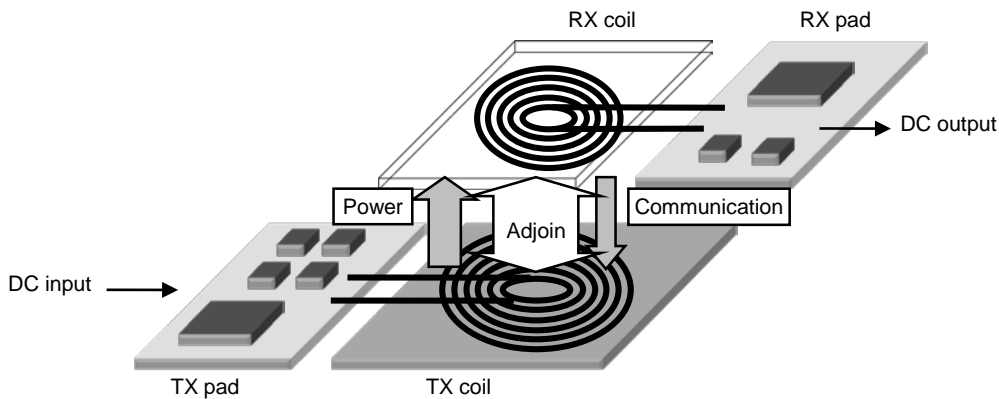


Figure 8.1 General outline of a wireless power system

8.2 General outline of wireless power RX system

The TC7765WBG includes a rectifier circuit which smoothes the RX coil current of the wireless power system; a digital control circuit; a modulation circuit which communicates between RX and TX.

A wireless power system can be constructed easily without the control of a MCU because the TC7765WBG includes a digital control circuit which can operate in standalone mode. The digital control circuit transmits the received power information to the TX after some calculations. By using the TC7765WBG as RX, the TX can take advantage of the received power information sent by the RX and a wireless power system can be constructed including FOD detection.

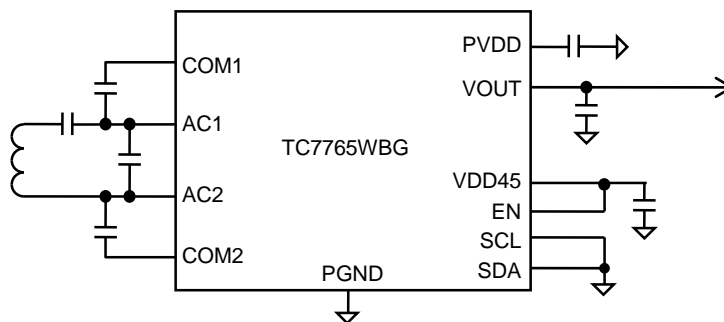


Figure 8.2 General outline of RX with the TC7765WBG

8.3 Control of TC7765WBG

8.3.1 Basic operation

The TC7765WBG incorporates a digital control circuit to realize communication with a TX. The TC7765WBG starts communication using WPC communication protocol when it receives power from a TX.

After entering the Power Transfer Phase, the output switch turns on. And STAT signal turns to “L”. The condition of enabling output is when EN is “H” or “Open”. Figure 8.3 shows a basic operation sequence.

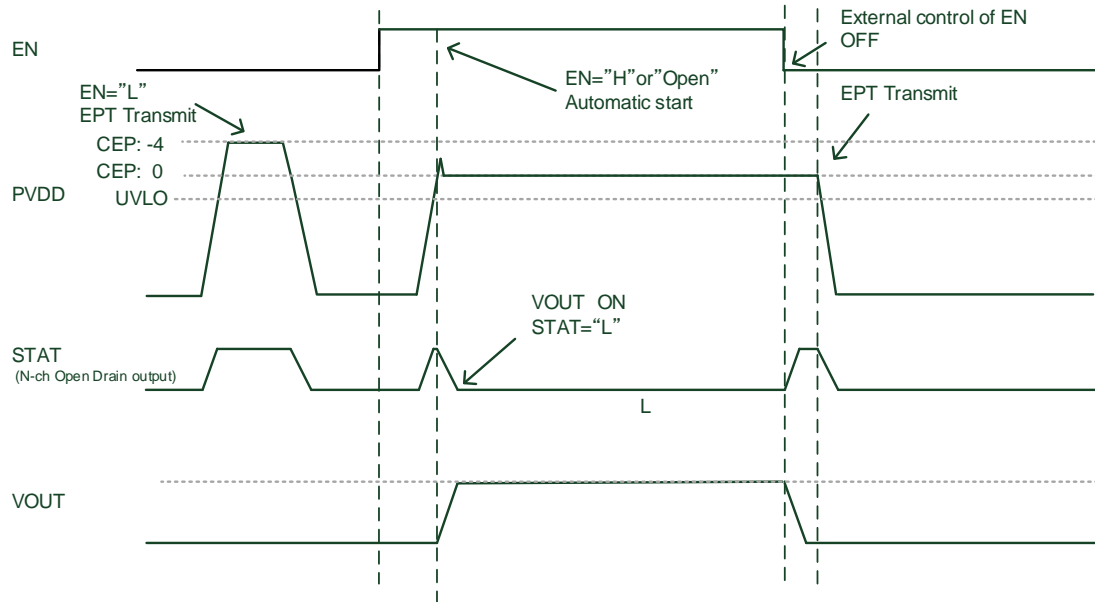


Figure 8.3 Basic operation (using EN control)

8.4 Control state machine

The state machine of the TC7765WBG consists of SHUTDOWN mode, STARTUP mode, OUTPUT mode and OVP mode. The wireless power system starts operation when transmitters TX coil and the TC7765WBGs RX coil are adjoined.

The state transition diagram of the wireless feeding control of the TC7765WBG is shown in the Figure 8.4. The operation state of each circuit in each mode is shown in the table 8.1.

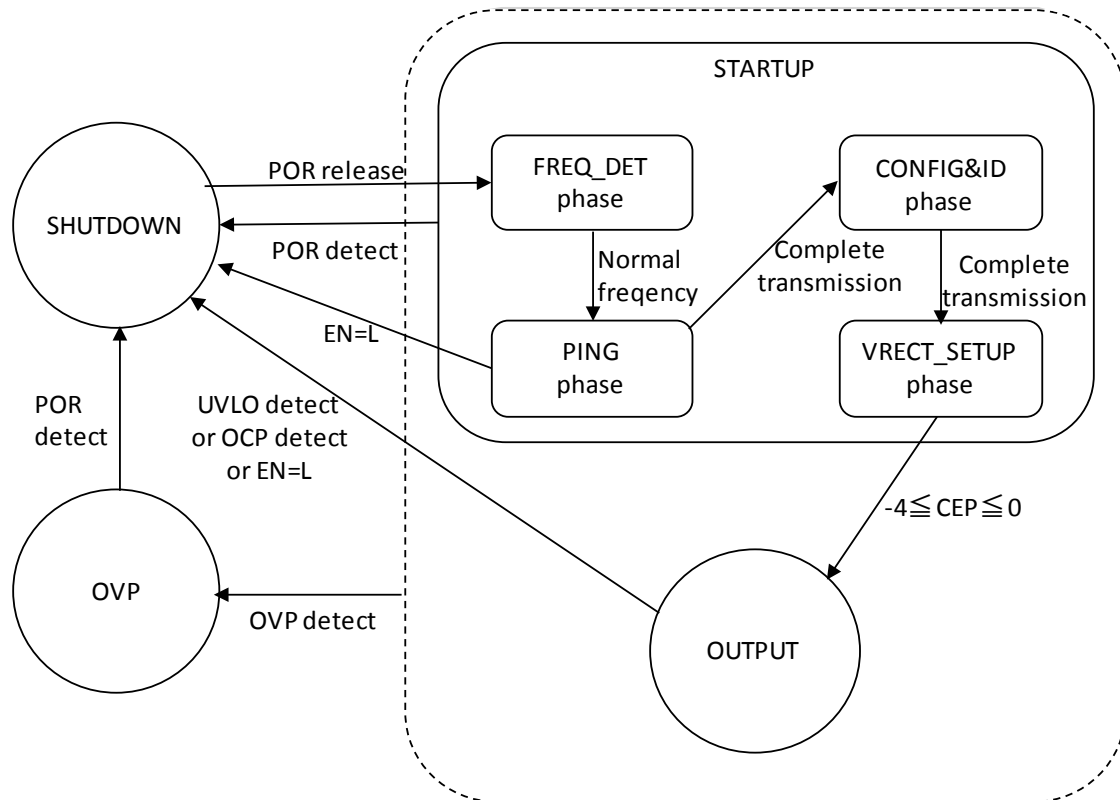


Figure 8.4 State transition diagram of TC7765WBG wireless power supply control

Table 8.1 Operating condition for each mode

| Wireless charge control mode | | Rectifier circuit | Packets (Header values) | VOUT output | UVLO | TSD | I ² C control | STAT output |
|------------------------------|-------------|---|----------------------------|----------------|-------|---------|-----------------------------|----------------|
| SHUTDOWN | | Diode bridge rectification | - | OFF | Valid | Invalid | Invalid | Hi-Z |
| STARTUP | FREQ_DET | Diode rectification | NA | OFF | Valid | Valid | Valid | Hi-Z |
| | PING | Diode rectification | 01h, 02h | OFF | Valid | Valid | Valid | Hi-Z |
| | CONFIG&ID | Diode rectification | 51h, 71h | OFF | Valid | Valid | Valid | Hi-Z |
| | VRECT_SETUP | Diode rectification | 02h, 03h 04h | OFF | Valid | Valid | Valid | Hi-Z |
| OUTPUT | | Diode rectification or synchronous rectification | 02h, 03h, 04h | ON | Valid | Valid | Valid | L |
| OVP | | Diode bridge rectifier + RECT_CLAMP | 02h | OFF | Valid | Valid | Valid | Hi-Z |

8.4.1 SHUTDOWN mode

SHUTDOWN mode is the status without detection of wired or wireless power supply. The detection judgment whether wireless power supply is on or not is done by internal monitoring of the PVDD terminal voltage (VRECT; the voltage generated by rectifying the RF wireless power).

When the VRECT is below the UVLO release voltage, TC7765WBG enters SHUTDOWN mode.

In SHUTDOWN mode, the digital control circuit, communication circuit and regulator circuits are stopped.

When the UVLO is released, TC7765WBG starts to operate the wireless power supply control and goes to STARTUP mode.

8.4.2 STARTUP mode

STARTUP mode is the status when the TC7765WBG detects wireless power, in which it certificates with TX and stabilizes VRECT. The status has 4 phases which automatically transit in the following sequence: FREQ_DET phase, PING phase, CONFIG&ID phase and VRECT_SETUP phase.

In the STARTUP mode the rectifier circuit works as diode rectifier in which the low-side MOSFETs are fixed to off and only the high-side MOSFETs work.

The condition of shifting to OUTPUT mode are:

- Over two CEP have transmitted to Tx,
- CEP value is from -4 to zero.

(1) FREQ_DET phase

In the FREQ_DET phase, TC7765WBG determines if the TX is compliant to the Qi standard. After UVLO is released, TC7765WBG starts detection of the frequency on AC1 and AC2. When the range of the frequency is over 80 kHz, TC7765WBG considers that the frequency is stable.

After confirming both the proper frequency and frequency stability, TC7765WBG shifts to the PING phase.

(2) PING phase

In the PING phase, TC7765WBG notifies detection of wireless power supply to the TX. TC7765WBG measures the rectifier output VRECT to determine its received power and sends a packet including header (01h) and the result of the received power calculation to the TX. After that the TC7765WBG automatically transitions to the CONFIG&ID phase.

In case of EN=L', TC7765WBG sends End Power Transfer Packet (Data:charge complete) instead of header 01h.

(3) CONFIG&ID phase

In the CONFIG&ID phase, TC7765WBG sends RX information to the TX. After it has elapsed in this phase, TC7765WBG sends a packet including header (71h), WPC version, maker code and serial code. Subsequently, after it sends a packet including header (51h), received power and timing code measured by the TC7765WBG.

Then TC7765WBG automatically shifts to VRECT_SETUP phase.

(4) VRECT_SETUP phase

In the VRECT_SETUP phase, VRECT is converged to its target value. After it has elapsed in this phase, TC7765WBG calculates an error value. After, TC7765WBG sends a packet including header (03h) and Control Error Packet (CEP) including the error value.

The condition of shifting to OUTPUT mode are:

- Over two CEP have transmitted to Tx,
- CEP value is from -4 to zero.

8.4.3 OUTPUT mode

In the OUTPUT phase, TC7765WBG provides power received from a wireless power supply to the load. In this mode, VRECT is controlled by Tx which is receiving CEP from TC7765WBG. Periodically, the TC7765WBG calculates the received power and sends a packet including header (04h) and received power. Maximum output current is 1.0 A. OCP current (IOCP) is set to 1.3 A. TC7765WBG sends EPT (Data:Over Current) when over current is detected.

8.4.4 OVP mode

This function is to avoid overvoltage of VRECT by the over voltage detection function of VRECT and the RECT_CLAMP function. If VRECT exceeds 15 V, TC7765WBG judges it as an over voltage. In such a case the TC7765WBG connects AC1 and AC2 to GND through external capacitors by switching CLMP1 and CLMP2 from Hi-Z to GND. The RX coil current flows through the capacitors, so that TC7765WBG can reduce VRECT.

When VRECT is less than 10V, from OVP mode is canceled.

8.4.5 Operation stop

Two methods can be used to stop the wireless power supply operation: EPT (End Power Transfer) messages and the communication timeout. When TC7765WBG activates any of its protection functions, it transmits an EPT message to the TX. The TX then stops its power transmission.

The communication timeout means that the TX does not receive any packet which TC7765WBG transmitted for a fixed period. Then the TX stops power transmission automatically.

9. Descriptions of functional details

9.1 Communication function of the wireless power system

In the STARTUP mode, when the UVLO is released and the frequency of rectifier is more than 80 kHz, the input is judged normal and communication (PING Phase) of the wireless power system automatically starts.

9.1.1 ASK modulation

Capacitors are connected between COM1 and AC1 and between COM2 and AC2. TC7765WBG communicate with TX by ASK modulation. The coil current is overlapped with the signals that TC7765WBG controls capacity load.

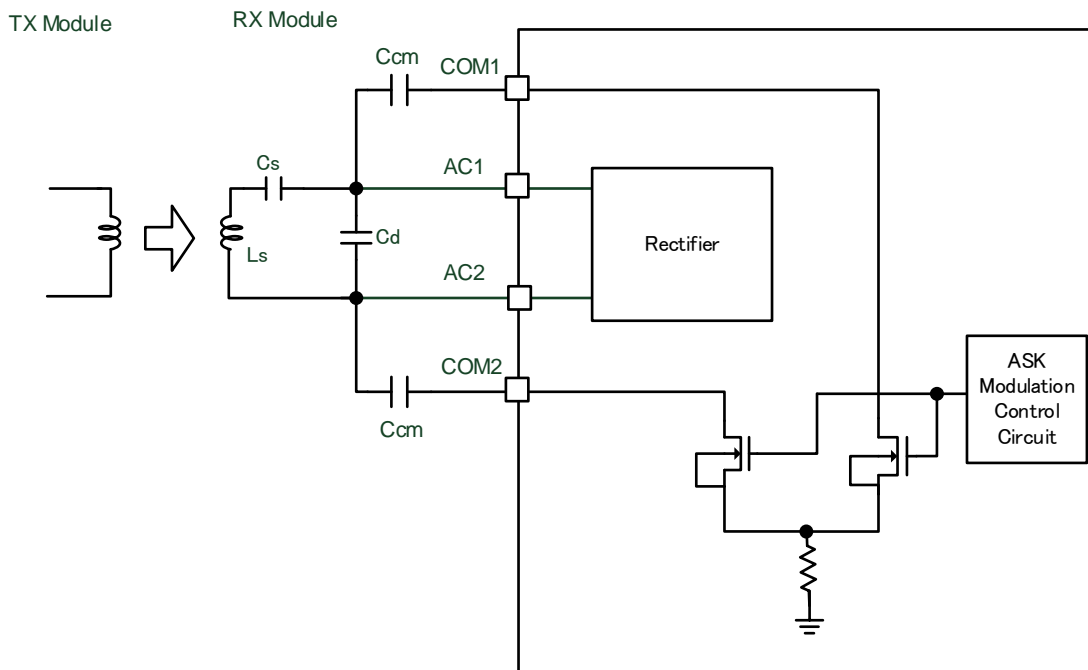


Figure 9.1 Connection diagram of ASK modulation

9.1.2 Communication protocol

(1) Bit Encoding Scheme

Bit chart of communication is as follows.

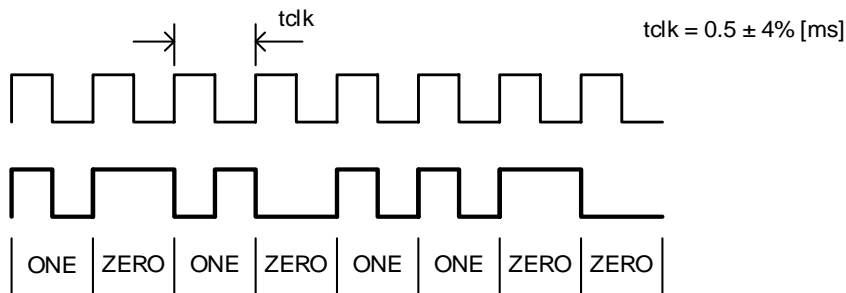


Figure 9.2 Example of the differential bi-phase encoding

(2) Byte Encoding Scheme

Byte chart of communication is as follows. Start bit: "ZERO", Stop bit: "ONE".
The order of the data bits is lsb first.

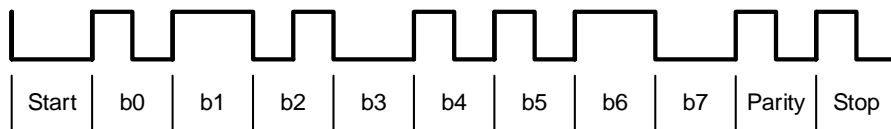


Figure 9.3 Example of the asynchronous serial format

(3) Packet Structure

Packets of communication consist of four parts; Preamble, Header, Message, and Checksum.

Preamble: 11bit (default) of ONE continuously.

Header: Indicates the kind of packet and specifies the size of the message that will be sent next.

Message: Data of each packet type.

Checksum: XOR value of Header and Message.

$$\text{Checksum} = \text{Header} + \text{Message}(0) + \text{Message}(1) + \dots + \text{Message}(\text{last})$$

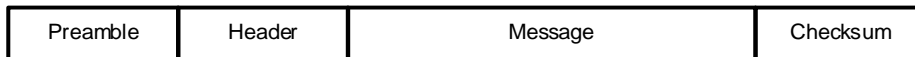


Figure 9.4 Packet format

9.1.3 Communication packets

The TC7765WBG transmits packets according to the following definitions.

- PING Phase

(1) **Signal Strength Packet (01h)**

Table 9.1 Strength Packet

| Packet | Header | | b7 | b6 | b5 | b4 | b3 | b2 | b1 | b0 |
|------------------------|--------|----|-----------------------|----|----|----|----|----|----|----|
| Signal Strength Packet | 01h | B0 | Signal Strength Value | | | | | | | |

Signal Strength Value:

It indicates the strength of the coupling between primary side and secondary side, which is calculated by monitoring VRECT.

- CONFIG & ID Phase

(2) **Identification Packet (71h)**

Table 9.2 Identification Packet

| Packet | Header | | b7 | b6 | b5 | b4 | b3 | b2 | b1 | b0 | |
|-----------------------|--------|----|---------------|-------------------------|----|----|---------------|----|----|-------|--|
| Identification Packet | 71h | B0 | Major Version | | | | Minor Version | | | | |
| | | B1 | (msb) | Manufacturer Code | | | | | | | |
| | | B2 | | | | | | | | (lsb) | |
| | | B3 | EXT | (msb) | | | | | | | |
| | | B4 | | Basic Device Identifier | | | | | | | |
| | | B5 | | | | | | | | | |
| | | B6 | | | | | | | | (lsb) | |

Major Version : Fixed to "01h"

Minor Version : Fixed to "01h"

Manufacturer Code : Indicates manufacture code. The code of Toshiba is "0033h".

EXT : Fixed to "EXT = "0"

Basic Device Identification

: Indicates the individual device ID.

(3) **Configuration Packet (51h)**

Table 9.3 Configuration Packet

| Packet | Header | | b7 | b6 | b5 | b4 | b3 | b2 | b1 | b0 | |
|----------------------|--------|----|-------------|----------|---------------|----|---------------|-------|----|----|--|
| Configuration Packet | 51h | B0 | Power Class | | Maximum Power | | | | | | |
| | | B1 | Reserved | | | | | | | | |
| | | B2 | Prop | Reserved | | | | Count | | | |
| | | B3 | Window Size | | | | Window Offset | | | | |
| | | B4 | Reserved | | | | | | | | |

Power Class : "00h"
 Maximum Power : "0Ah" (5 W)
 Prop : "00h"
 Count : "00h"
 Window Side : "04h"
 Window Offset : "01h"

- VRECT_SETUP Phase / STANDBY Phase

(4) **Control Error Packet (03h)**

Table 9.4 Control Error Packet

| Packet | Header | | b7 | b6 | b5 | b4 | b3 | b2 | b1 | b0 |
|----------------------|--------|----|---------------------|----|----|----|----|----|----|----|
| Control Error Packet | 03h | B0 | Control Error Value | | | | | | | |

(5) **Received Power Packet (04h)**

Table 9.5 Received Power Packet

| Packet | Header | | b7 | b6 | b5 | b4 | b3 | b2 | b1 | b0 |
|-----------------------|--------|----|----------------------|----|----|----|----|----|----|----|
| Received Power Packet | 04h | B0 | Received Power Value | | | | | | | |

Received Power Value: Indicates received power including FOD compensation.

(6) End power transfer packet (02h)

Table 9.6 End Power Transfer Packet

| Packet | Header | | b7 | b6 | b5 | b4 | b3 | b2 | b1 | b0 |
|---------------------------|--------|----|--------------------------|----|----|----|----|----|----|----|
| End Power Transfer Packet | 02h | B0 | End Power Transfer Value | | | | | | | |

End Power Transfer Value: Signal of End Power Transfer is transmitted according to Table 9.7.

Table 9.7 End Power Transfer Value

| Reason | Value | Condition |
|------------------|-------|--|
| Unknown | 00h | Unused |
| Charge Complete | 01h | When wireless charging off due to EN = "L" |
| Internal Fault | 02h | Unused |
| Over Temperature | 03h | Internal and external over temperature detection |
| Over Voltage | 04h | At the detection of over voltage limitation |
| Over Current | 05h | At the detection of over current limitation |
| Battery Failure | 06h | Unused |
| Reconfigure | 07h | Unused |
| No Response | 08h | Unused |

9.2 Rectifier circuit

9.2.1 Rectifier modes

The rectifier circuit has 3 modes: synchronous rectification, diode rectification, and diode bridge mode. TC7765WBG automatically switches the modes.

In SHUTDOWN mode, the rectifier operates in the diode bridge mode. In this mode, all MOSFETs are fixed to OFF and the rectifier operates over the MOSFETs body diode.

In STARTUP mode, the rectifier operates in the diode rectifier mode. In this mode, the low side MOSFETs are fixed to OFF. The rectifier operates by turning on and off only the high side MOSFETs.

In OUTPUT mode, the rectifier operates in the synchronous rectification mode by turning on and off all MOSFETs. When output current is low, the rectifier operates in the diode rectifier mode.

9.2.2 RECT_CLAMP function

The RECT_CLAMP function suppresses over voltages of VRECT. The clamping functions circuitry can be seen in Figure 9.5. Excessive coil current potentially generating an over voltage at the internal recitfier output will be shunted to GND through a capacitive load connected to the IC's CLMP terminals and the IC internal MOSFETs. This suppresses the excessive rise of VRECT.

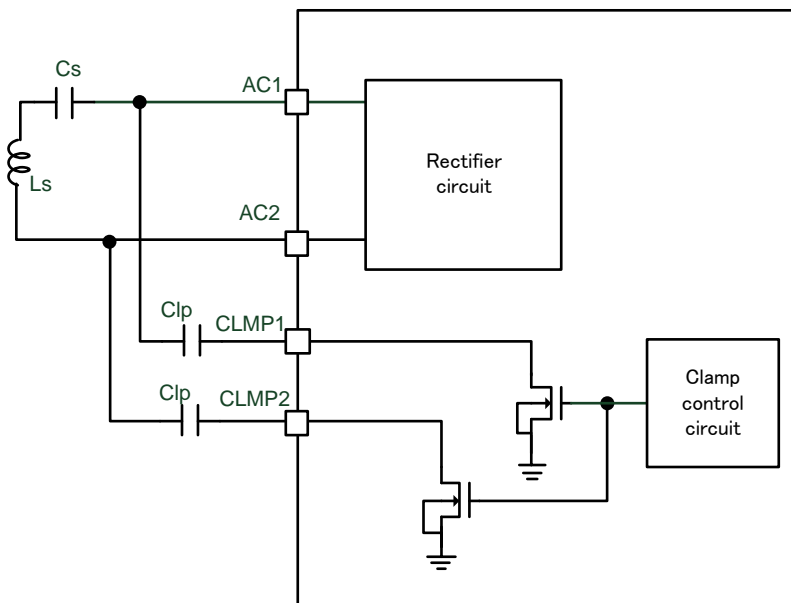


Figure 9.5 Connection diagram of clamp circuit

9.3 FOD function

The FOD function is used to calculate losses of received power in the mobile device. TC7765WBG can revise the actual received power, measured by the rectifier current, with two external resistors in the FOD and OFFSET terminals.

9.3.1 FOD Terminal

It is possible to change the slope of received power.
Connect resistor (0 to 1.25 k Ω) to GND.

9.3.2 OFFSET Terminal

It is possible to change the offset of received power.
Connect resistor (0 to 20 k Ω) to GND.

9.4 Protection functions

9.4.1 Under voltage lockout (UVLO) function

Under voltage lockout (UVLO) function avoids errors caused by too low VRECT voltages. Rectifying circuit UVLO detection condition is that the voltage of VRECT falls below 2.6 V (typ.). UVLO function is released when the voltage of VRECT exceeds 2.7 V (typ.).

9.4.2 Over voltage detection (WPT_OVP) function

Over voltage detection (WPT_OVP) function avoids errors caused by too high VRECT voltages. Detection condition of WPT_OVP function is that the voltage of PVDD exceeds 15V (typ.). When WPT_OVP function worked, TC7765WBG transmit overvoltage EPT three times and finish communication control of the wireless power. In addition, when VRECT is over 15 V, the clamping circuit of the rectifier is turned on, and a clamping circuit is off when VRECT is less than 10 V.

9.4.3 Over current protection (OCP) function

Over current detection (OCP) function is a function to control an output current. A detection condition of the OCP function is to exceed a limited output current. The OCL detection current is 1.3 A (typ.).

9.4.4 Thermal shutdown (TSD) function

Thermal shutdown (TSD) function avoids the IC destruction caused by rising chip internal temperature. The detection condition of TSD function is that the internal temperature exceeds 150°C (typ.). When TSD is detected, the output of LDO is turned off. In case the internal temperature falls below 130°C (typ.), TSD function is released automatically and LDO is turned on again. In case the TSD status continues for 200ms or more, the output of the LDO turns off and power transmission is finished by transmitting an EPT message to the TX (03h: Over Temperature).

10. Absolute Maximum Ratings (Ta = 25°C)

Table 10.1 Absolute Maximum Ratings

| Characteristics | Symbol | Rating | Unit | Remarks |
|-----------------------|------------------|-------------|------|----------|
| Supply voltage | VRECTMAX | -0.3 to 18 | V | (Note 1) |
| Input voltage (1) | V _{I1} | -0.3 to 18 | V | (Note 2) |
| Input voltage (2) | V _{I2} | -0.3 to 30 | V | (Note 3) |
| Input voltage (3) | V _{I3} | -0.3 to 8 | V | (Note 4) |
| Input voltage (4) | V _{I4} | -0.3 to 5.6 | V | (Note 5) |
| Operating temperature | T _{opr} | -40 to 85 | °C | |
| Junction temperature | T _j | 150 | °C | |
| Storage temperature | T _{stg} | -55 to 150 | °C | |

Note: The absolute maximum ratings of a semiconductor devices are a set of ratings that must not be exceeded, even for a moment. Do not exceed any of these ratings. Exceeding the rating(s) may cause the device to break down, damage, and may result injury by explosion or combustion. Please use the IC within the specified operating ranges.

In addition, please assume it "PGND = 0 V".

Note 1: Applies to PVDD terminal only

Note 2: Applies to AC1, AC2, COM1, COM2, CLMP1, CLMP2 and VOUT terminals

Note 3: Applies to TEST1 and TEST2 terminals

Note 4: Applies to VPP terminal

Note 5: Applies to terminal except above terminals

11. Electrical Characteristics

11.1 DC characteristics Common Circuit, Digital Controller

Table 11.1 DC characteristics Common Circuit, Digital Controller

(Unless otherwise specified, VRECT = 7 V, PGND = 0 V, Ta = 25°C)

| Characteristics | Symbol | Test condition | Min | Typ. | Max | Unit | Terminal | |
|---------------------------|----------------------|--|---------------------------|------|------|------|----------|------|
| Operation voltage | VOPE1 | - | 3.5 | - | 15 | V | PVDD | |
| UVLO detection voltage | VUVLO_ON | VRECT = 7 V to 0 V | 2.5 | - | 2.7 | V | PVDD | |
| UVLO release voltage | VUVLO_OFF | VRECT = 0 V to 7 V | - | - | 2.9 | V | PVDD | |
| Quiescent current | ICC | VRECT = 7 V AC1 = AC2 = Open 5 V LDO off | - | 2.5 | 6.0 | mA | PVDD | |
| Input voltage | High level | VIH1 | - | 1.4 | - | V | EN | |
| | Low level | VIL1 | - | - | 0.4 | | | |
| Input current | High level | I _{IH1} | VIH1 = V _{OUT45} | 20 | - | 75 | μA | EN |
| | Low level | I _{IL1} | VIL1 = GND | -0.6 | - | 0.6 | | |
| Output voltage | Low level | VOL1 | I _{OUT} = -1 mA | 0 | - | 0.4 | V | STAT |
| VDD45 voltage | VDD45 | - | 4.25 | - | 4.75 | V | VDD45 | |
| Oscillator frequency | f _{CLK} | - | 3.84 | 4.0 | 4.16 | MHz | | |
| TSD detection temperature | T _{TSD_ON} | - | 135 | 150 | 165 | °C | | |
| TSD release temperature | T _{TSD_OFF} | - | 120 | - | - | °C | | |

11.2 DC Characteristics Rectifier, Modulator

Table 11.2 DC Characteristics Rectifier, Modulator

(Unless otherwise specified, VRECT = 7 V, PGND = 0 V, Ta = 25°C)

| Characteristics | Symbol | Test condition | Min | Typ. | Max | Unit | Terminal | |
|--------------------------------|-------------------|---|---------------------------|------|-----|------|--------------|----------|
| Rectifier MOSFET on-resistance | High-side | RONH_AC | I _{DS} = -100 mA | - | 45 | - | mΩ | AC1, AC2 |
| | Low-side | RONL_AC | I _{DS} = 100 mA | - | 30 | - | | |
| Clamper MOSFET on-resistance | RON_CLMP | I _{DS} = 100 mA | - | - | 1.5 | Ω | CLMP1, CLMP2 | |
| Modulator output resistance 1 | R _{COM1} | COM2 open Resistance between COM1 and PGND | 45 | - | 65 | Ω | COM1 | |
| Modulator output resistance 2 | R _{COM2} | COM1 open Resistance between COM2 and PGND | 45 | - | 65 | Ω | COM2 | |

11.3 DC Characteristics of OUTPUT

Table 11.3 DC Characteristics OUTPUT

(Unless otherwise specified, PGND = 0 V, Ta = 25°C)

| Characteristics | Symbol | Test condition | Min | Typ. | Max | Unit | Terminal |
|----------------------|-------------------|----------------|-----|------|-----|------|----------|
| OCP current | I _{OCP1} | SET_OCL = 11b | 1.1 | 1.3 | 1.5 | A | VOUT |
| Discharge resistance | R _{DCHG} | - | - | 8 | - | kΩ | VOUT |

11.4 AC Characteristics I²C Interface

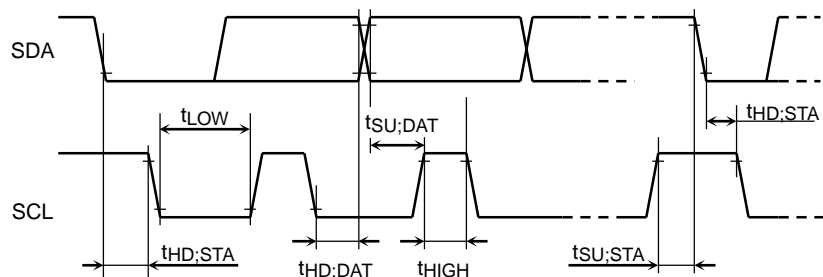


Table 11.4 AC Characteristics

Unless otherwise specified, VRECT = 7 V, PGND = 0 V, Ta = 25°C

| Characteristics | Symbol | Min | Typ. | Max | Unit |
|------------------------------|---------------------|-----|------|-----|------|
| Operation clock frequency | f _{SCL} | - | - | 400 | kHz |
| Hold time of repeated start | t _{HD:STA} | 0.6 | - | - | μs |
| Setup time of repeated start | t _{SU:STA} | 0.6 | - | - | μs |
| Data hold time | t _{HD:DAT} | 0 | - | 0.9 | μs |
| Data setup time | t _{SU:DAT} | 100 | - | - | ns |
| Low term of SCL signal | t _{LOW} | 1.3 | - | - | μs |
| High term of SCL signal | t _{HIGH} | 0.6 | - | - | μs |

12. Application Circuit

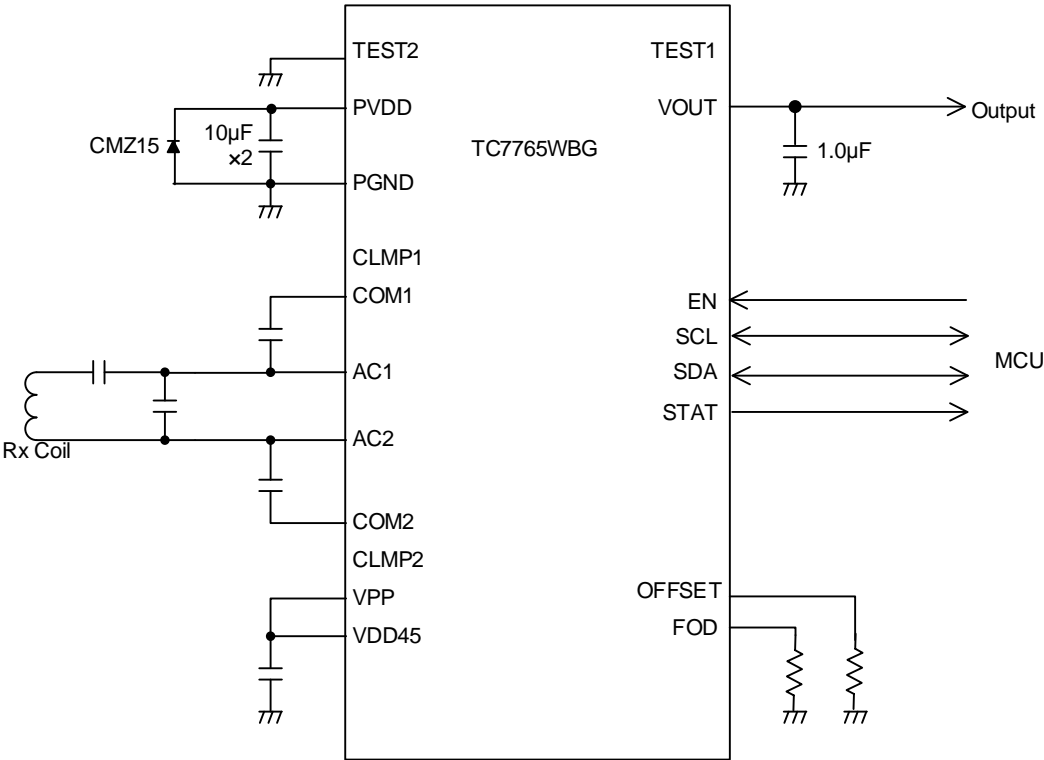
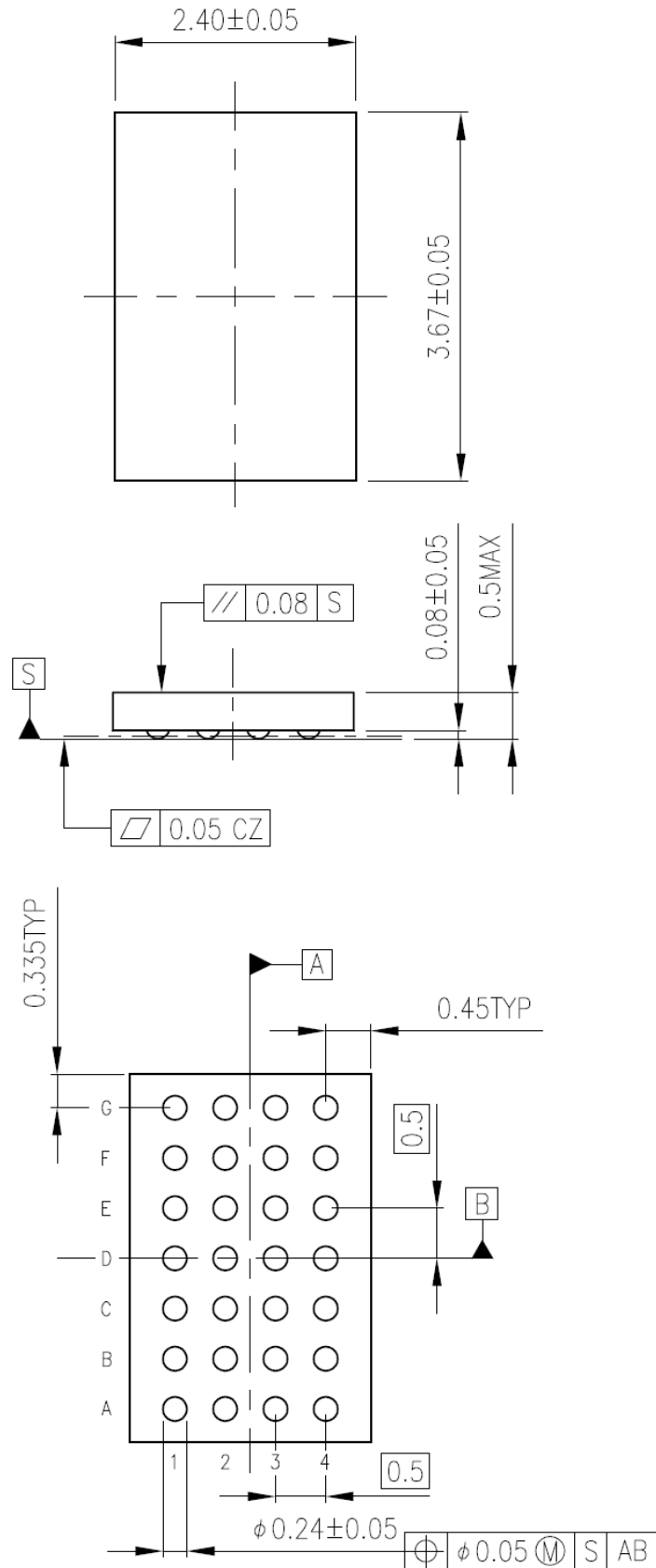


Figure 12.1 Application circuit

13. Package dimensions

S-XFLGA28-0304-0.50-001

Unit: mm



Weight: 10 mg (typ.)

RESTRICTIONS ON PRODUCT USE

- Toshiba Corporation, and its subsidiaries and affiliates (collectively "TOSHIBA"), reserve the right to make changes to the information in this document, and related hardware, software and systems (collectively "Product") without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA's written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. **TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.**
- **PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE").** Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, devices related to electric power, and equipment used in finance-related fields. **IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT.** For details, please contact your TOSHIBA sales representative.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- **ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.**
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. **TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.**