High Power Pump Express™ Plus-Compatible Digital PWM AC/DC Controller

1.0 Features

- Supports MediaTek Pump Express™ technology fast charge protocol
- Universal input off-line controller for applications up to 15W output power
- No-load power consumption < 30mW at 230V_{AC} along with fast dynamic load response and short turn-on delay in typical 15W adapter applications
- PrimAccurate™ primary-side feedback eliminates opto-isolators and simplifies design
- Adaptive multi-mode PWM/PFM control improves efficiency
- Proprietary optimized 79kHz maximum PWM switching frequency with quasi-resonant operation achieves best size, efficiency and common mode noise
- Active start-up scheme enables fastest possible start-up
- Tight constant-voltage regulation across line and load range
- User-configurable 5-level cable drop compensation provides design flexibility
- EZ-EMI® design enhances manufacturability
- No external loop compensation components required
- Built-in single-point fault protections against output short-circuit, output over-voltage, output over-current, and current-sense-resistor-short fault
- Dedicated pin for external over-temperature protection
- Tight constant current control enables output current limit and over-load protection
- No audible noise over entire operating range

2.0 Description

The iW1788 is a high performance AC/DC power supply controller which uses digital control technology to build peak current mode PWM flyback power supplies and is compatible with MediaTek's Pump Express™ Plus fast charge protocol. With PrimAccurate™ digital primary-side control technology integrated, the iW1788 enables simple, low component count power supplies for universal input off-line applications requiring low BOM cost, high performance solutions. The iW1788 removes the need for secondary feedback circuitry and loop compensation components while achieving excellent stability and line and load regulation.

The Pump Express Plus fast charge protocol enables communication between a smartphone and a wall adapter designed with the iW1788. The high power protocol allows the smartphone to send commands back to the controller to increase the output voltage of the adapter above the default 5V output, or below the default voltage to optimize charge time. The built-in power limiting function increases the output current of the adapter as the voltage output decreases and decreases the output current of the adapter as the voltage output increases. This allows the designer to minimize the size of the external transformer without sacrificing performance. See section 9.14 for more information on this function.

The iW1788 works with an external power MOSFET to allow for an output power of up to 15W. The device operates in quasi-resonant mode to provide high efficiency and integrates a number of key built-in protection features, such as EZ-EMI technology, pulse-by-pulse waveform analysis for faster dynamic load response and a full range of protection features from over-temperature, over-voltage and short-circuit.

Dialog's innovative proprietary technology ensures that power supplies built with the iW1788 can achieve both highest average active efficiency and less than 30mW no-load power consumption in 15W output power applications, and have fast yet smooth start-up with a wide range of capacitive loads at output voltages up to 12V.

3.0 Applications

- Compact AC/DC adapter/chargers for cell phones, PDAs, digital still cameras
- Fast charge enabled adapters for smartphones
- Universal input AC/DC adapters (7.5W - 15W)

High Power Pump Express™ Plus-Compatible Digital PWM AC/DC Controller

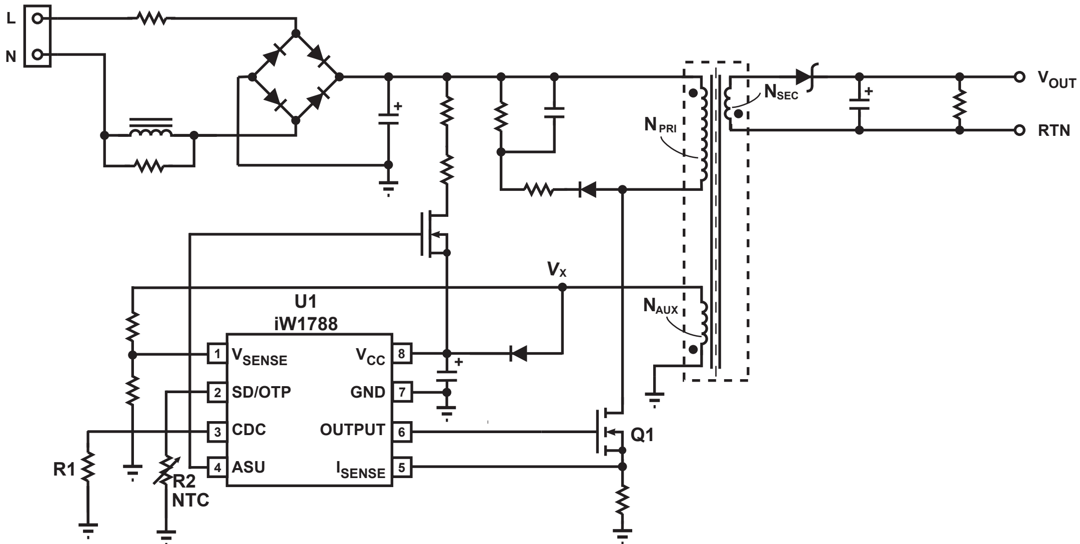


Figure 3.1 : iW1788 Typical Application Diagram

4.0 Pinout Description

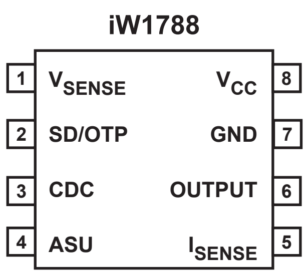


Figure 4.1 : 8-Lead SOIC-8 Package

Pin #	Name	Type	Pin Description
1	V_{SENSE}	Analog Input	Auxiliary voltage sense (used for primary regulation).
2	SD/OTP	Analog Input	External shutdown control. Used for external over-temperature protection (OTP) by connecting an NTC resistor from this pin to Ground.
3	CDC	Analog Input	Used for external cable drop compensation (CDC) configuration.
4	ASU	Output	Control signal for active start-up device (BJT or depletion mode NFET).
5	I_{SENSE}	Analog Input	Primary current sense. Used for cycle-by-cycle peak current control and limit.
6	OUTPUT	Output	Gate drive for external MOSFET switch.
7	GND	Ground	Ground.
8	V_{CC}	Power Input	Power supply for control logic.

High Power Pump Express™ Plus-Compatible Digital PWM AC/DC Controller

5.0 Absolute Maximum Ratings

Absolute maximum ratings are the parameter values or ranges which can cause permanent damage if exceeded. For maximum safe operating conditions, refer to Electrical Characteristics in Section 6.0.

Parameter	Symbol	Value	Units
DC supply voltage range (pin 8, I_{CC} = 20mA max)	V_{CC}	-0.3 to 25.0	V
Continuous DC supply current at V_{CC} pin (V_{CC} = 15V)	I_{CC}	20	mA
ASU output (pin 4)		-0.3 to 19.0	V
OUTPUT (pin 6)		-0.3 to 20.0	V
V_{SENSE} input (pin 1, I_{Vsense} ≤ 10mA)		-0.7 to 4.0	V
I_{SENSE} input (pin 5)		-0.3 to 4.0	V
SD (pin 2)		-0.3 to 4.0	V
CFG (pin 3, I_{CFG} ≤ 20mA)		-0.8 to 4.0	V
Maximum junction temperature	T_{JMAX}	150	°C
Operating junction temperature	T_{JOPT}	-40 to 150	°C
Storage temperature	T_{STG}	–65 to 150	°C
Thermal resistance junction-to-ambient	θ_{JA}	160	°C/W
ESD rating per JEDEC JESD22-A114		±2,000	V
Latch-up test per JESD78A		±100	mA

6.0 Electrical Characteristics

V_{CC} = 12V, -40°C ≤ T_A ≤ +85°C, unless otherwise specified.

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
V_{SENSE} SECTION (Pin 1)						
Input leakage current	I_{BVS}	V_{SENSE} = 2V			1	µA
Nominal voltage threshold	$V_{SENSE(NOM)}$	T_A=25°C, negative edge, V_{OUT} = 12V	1.70	1.75	1.80	V
V_{SENSE}-based output OVP threshold with no CDC compensation (Note 1)	$V_{SENSE(MAX)}$	T_A=25°C, negative edge, V_{OUT} = 5V		0.844		V
		T_A=25°C, negative edge, V_{OUT} = 12V		2.025		V
I_{SENSE} SECTION (Pin 5)						
Over-current threshold	V_{OCP}		1.11	1.15	1.19	V
I_{SENSE} regulation upper limit (Note 2)	$V_{IPK(HIGH)}$			1.00		V
I_{SENSE} regulation lower limit (Note 2)	$V_{IPK(LOW)}$			0.1		V
Input leakage current	I_{LK}	I_{SENSE} = 1.0V			1	µA
SD/OTP SECTION (Pin 2)						
Shutdown threshold (falling edge)	$V_{SD\text{-}TH(F)}$		0.95	1.0	1.05	V
Shutdown threshold before start-up	$V_{SD\text{-}TH(SD\_F)}$		1.14	1.2	1.26	V
Shutdown current source	I_{SD}		95	100	105	µA
CDC SECTION (Pin 3)						
Input leakage current	I_{CDC}	V_{CDC} = 1.0V			2.5	µA
OUTPUT SECTION (Pin 6)						
Driver pull-down ON-resistance	$R_{DS(ON)PD}$	I_{SINK} = 5mA		12		Ω
Driver pull-up ON-resistance	$R_{DS(ON)PU}$	I_{SOURCE} = 5mA		80		Ω
Rise time (Note 2)	t_R	T_A = 25°C, C_L = 330pF 10% to 90%		95		ns
Fall time (Note 2)	t_F	T_A = 25°C, C_L = 330pF 90% to 10%		14		ns

6.0 Electrical Characteristics (cont.)

V_{CC} = 12V, -40°C ≤ T_A ≤ 85°C, unless otherwise specified (Note 1)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Switching frequency (Note 3)	f_{SW}	> 50% load		79		kHz
Fast Charge Control SECTION (Secondary Output Current - Affected by R_S and N)						
Command current programming levels (Note 4 & 5)	$I_{CONTROL\_L}$		95		130	mA
	$I_{CONTROL\_H}$		250		300	mA
Output voltage accuracy during fast charge (Note 4 & 5)	V_{OUT}	V_{OUT} = 3.6V to 4.8V	-7.5		7.5	%
	V_{OUT}	V_{OUT} = 5V to 12V	-5		5	%
Watchdog timeout (Note 5)	T_{WD}		180	190	220	ms
V_{CC} SECTION (Pin 8)						
Operating voltage (Note 2)	$V_{CC(MAX)}$				20	V
Start-up threshold	$V_{CC(ST)}$	V_{CC} rising	12.7	13.7	14.7	V
Under-voltage lockout threshold	$V_{CC(UVL)}$	V_{CC} falling	5.2	5.5	5.8	V
Start-up current	$I_{IN(ST)}$	V_{CC} = 12V		7.6		μA
Quiescent current	I_{CCQ}	C_L = 330pF, V_{SENSE} = 1.5V		4.1		mA
ASU SECTION (Pin 4)						
Maximum operating voltage (Note 2)	$V_{ASU(MAX)}$				16	V
Resistance between V_{CC} and ASU	R_{Vcc_ASU}			1100		kΩ

Notes:

Note 1: See Section 9.12 for more details on CDC functionality.

Note 2: These parameters are not 100% tested. They are guaranteed by design and characterization.

Note 3: Operating frequency varies based on the load conditions, see Section 9.6 for more details.

Note 4. R_S and N must be set for an output of 1.65A in 5V setting.

Note 5. See Section 9.14 for details.

7.0 Typical Performance Characteristics

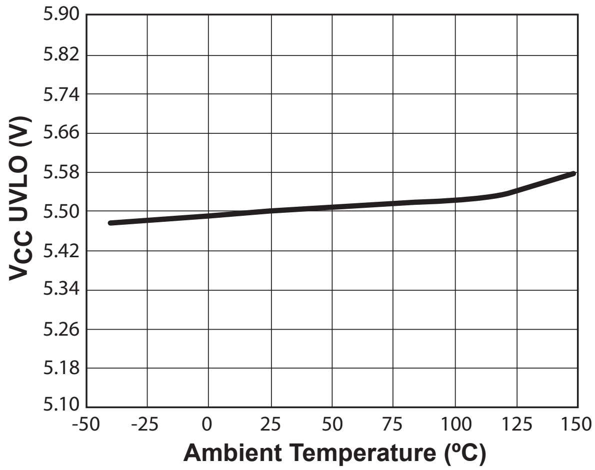


Figure 7.1 : V_{CC} UVLO vs. Temperature

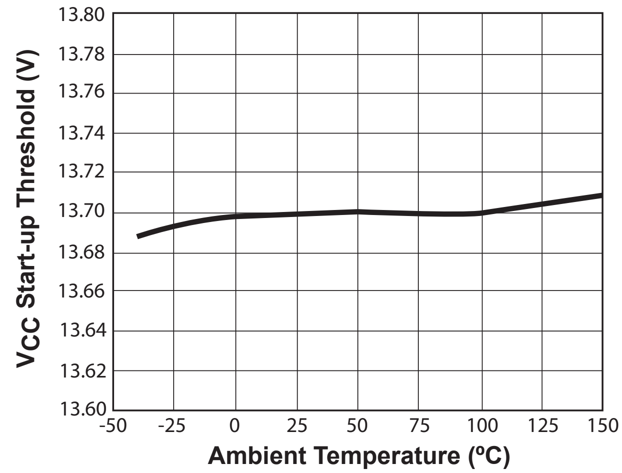


Figure 7.2 : Start-up Threshold vs. Temperature

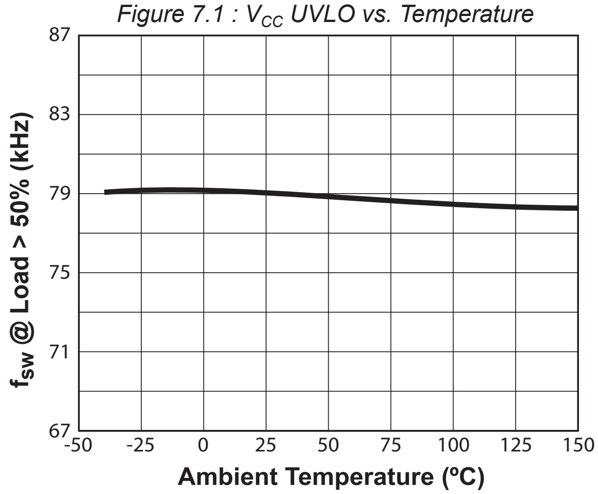


Figure 7.3 : Switching Frequency vs. Temperature[1]

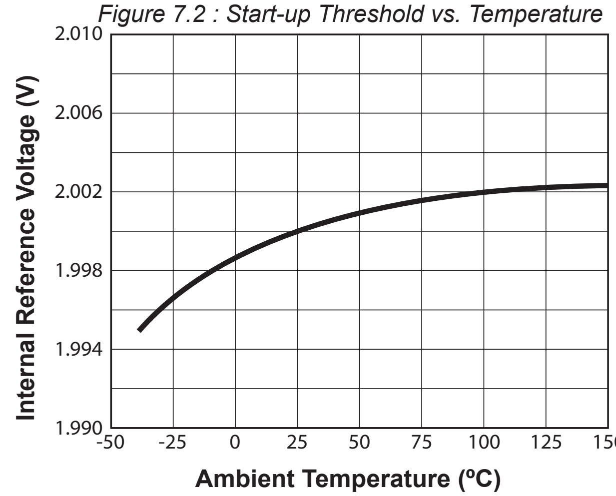


Figure 7.4 : Internal Reference vs. Temperature

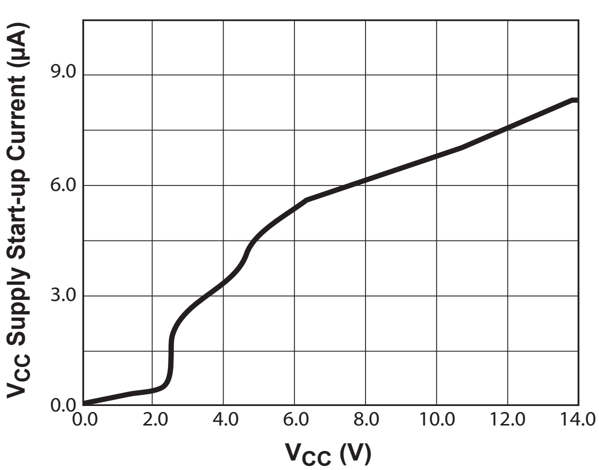


Figure 7.5 : V_{CC} Supply Start-up Current vs. V_{CC}

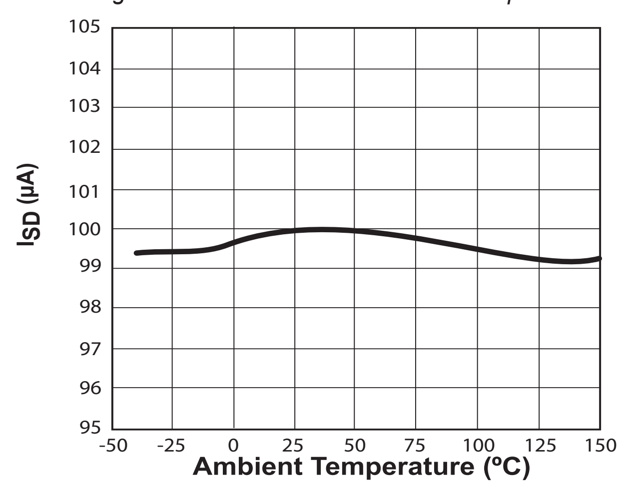


Figure 7.6 : I_{SD} vs. Temperature

Notes:

Note 1. Operating frequency varies based on the load conditions, see Section 9.6 for more details.

High Power Pump Express™ Plus-Compatible Digital PWM AC/DC Controller

8.0 Functional Block Diagram

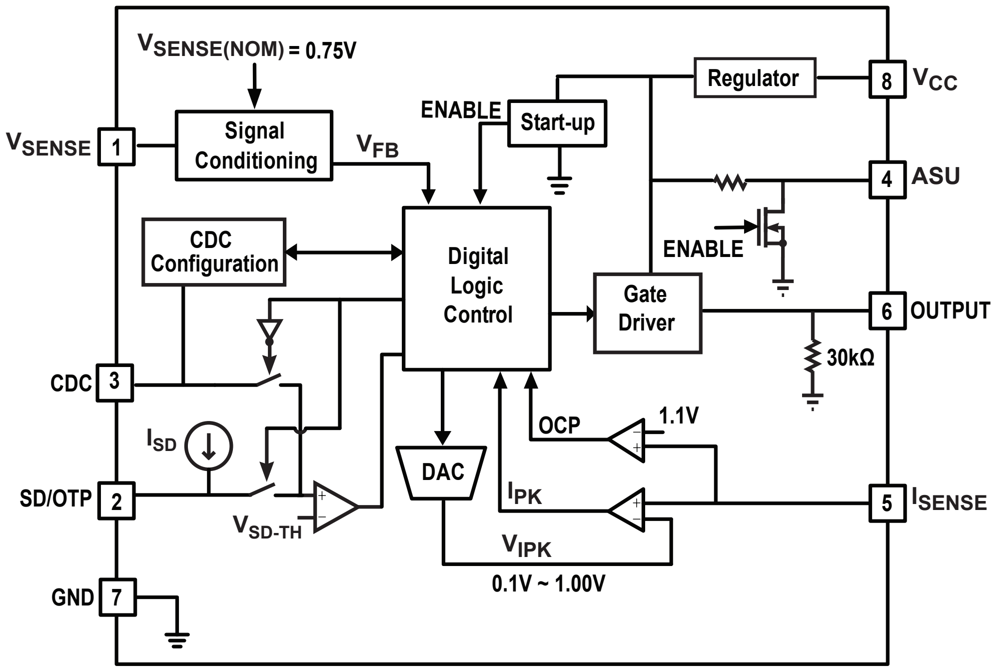


Figure 8.1 : iW1788 Functional Block Diagram

9.0 Theory of Operation

The iW1788 is a digital controller that uses a proprietary primary-side control technology to eliminate the opto-isolated feedback and secondary regulation circuits required in traditional designs. This results in a low-cost solution for low power AC/DC adapters. The core PWM processor uses fixed-frequency Discontinuous Conduction Mode (DCM) operation at higher power levels and switches to variable frequency operation at light loads to maximize efficiency. Furthermore, Dialog's digital control technology enables fast dynamic response, tight output regulation, and full-featured circuit protection with primary-side control.

The block diagram in Figure 8.1 illustrates the iW1788 operating in peak current mode control. The digital logic control block generates the switching on-time and off-time information based on the output voltage and current feedback signal and provides commands to dynamically control the external MOSFET gate voltage. The I_{SENSE} is an analog input configured to sense the primary current in a voltage form. In order to achieve the peak current mode control and cycle-by-cycle current limit, the V_{IPK} sets the threshold for the I_{SENSE} to compare with, and it varies in the range of 0.1V (typical) to 1.00V (typical) under different line and load conditions. The system loop is automatically compensated internally by a digital error amplifier. Adequate system phase margin and gain margin are guaranteed by design and no external analog components are required for loop compensation. The iW1788 uses an advanced digital control algorithm to reduce system design time and increase reliability.

Furthermore, accurate secondary constant current operation is achieved without the need for any secondary-side sense and control circuits.

The iW1788 uses adaptive multi-mode PWM/PFM control to dynamically change the MOSFET switching frequency for efficiency, EMI, and power consumption optimization. In addition, it achieves unique MOSFET quasi-resonant switching to further improve efficiency and reduce EMI. Built-in single-point fault protection features include over-voltage protection (OVP), output short-circuit protection (SCP), over-current protection (OCP), and I_{SENSE} fault detection.

Dialog's digital control scheme is specifically designed to address the challenges and trade-offs of power conversion design. This innovative technology is ideal for balancing new regulatory requirements for green mode operation with more practical design considerations such as minimum cost, smallest size, and high performance output control.

9.1 Pin Detail

Pin 1 – V_{SENSE}

Sense signal input from auxiliary winding. This provides the secondary voltage feedback used for output regulation.

Pin 2 – SD/OTP

External shutdown control. If the voltage at this pin is lower than 1.2V (typical) at the beginning of start-up or lower than 1.0V(typical) during normal operation, then the IC shuts down. Leave this pin unconnected if the shutdown control is not used (refer to Section 9.14).

Pin 3 – CDC

Used to configure external cable drop compensation (CDC) at the beginning of start-up.

Pin 4 – ASU

Control signal for active start-up device. This signal is pulled low after start-up is finished to cut off the active device.

Pin 5 – I_{SENSE}

Primary current sense. Used for cycle-by-cycle peak current control and limit.

Pin 6 – OUTPUT

Gate drive for the external power MOSFET switch.

Pin 7 – GND

Ground.

Pin 8 – V_{CC}

Power supply for the controller during normal operation. The controller starts up when V_{CC} reaches 12.0V (typical), and shuts down when the V_{CC} voltage drops below 6.5V (typical). A decoupling capacitor of 0.1 µF or so should be connected between the V_{CC} pin and GND.

9.2 Active Start-up and Adaptively Controlled Soft-Start

The iW1788 features an innovative proprietary soft-start scheme to achieve fast yet smooth build-up of output voltage with a wide range of output loads, including capacitive loads typically from 330µF to 6,000µF, and for output voltages covering typically from 5V to 12V. In addition, the active start-up schemes enable the shortest possible turn-on delay without sacrificing no-load power loss.

Refer to Figure 3.1 for active start-up circuits using external depletion mode N-FET. Prior to start-up, the ENABLE signal is low, and the ASU pin voltage closely follows the V_{CC} pin voltage, as shown in Figure 9.1. Consequently, the depletion mode N-FET is turned on, allowing the start-up current to charge the V_{CC} bypass capacitor. When the V_{CC} bypass capacitor is charged to a voltage higher than the start-up threshold $V_{CC(ST)}$, the ENABLE signal becomes active and the iW1788 begins to perform initial OTP check (see Section 9.14), followed by CDC configuration (see Section 9.12). Afterwards, the iW1788 commences soft-start function. During the soft-start process, the primary-side peak current is limited cycle-by-cycle by the I_{PEAK} comparator. The whole soft-start process can break down into several stages based on the output voltage levels, which is indirectly sensed by V_{SENSE} signal at the primary side. At different stages, the iW1788 adaptively controls the switching frequency and primary-side peak current so that the output voltage can always build up very fast at the early stages and smoothly transition into the desired regulation voltage at the final stage, regardless of any capacitive and resistive loads that the applications may incur.

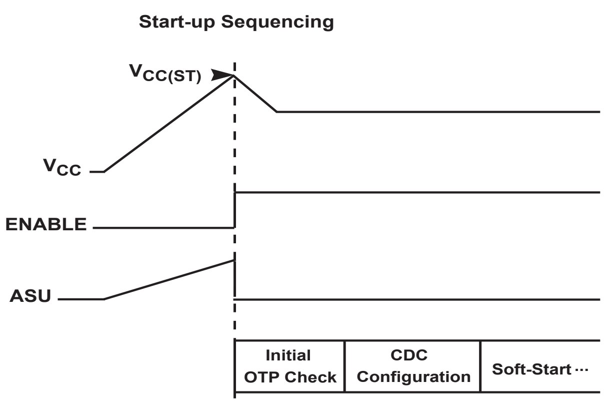


Figure 9.1: Start up Sequencing Diagram

As the ENABLE signal initiates the soft-start process, it also pulls down the ASU pin voltage at the same time, which turns off the depletion mode N-FET, thus minimizing the no-load standby power consumption.

If at any time the V_{CC} voltage drops below the under-voltage lockout (UVLO) threshold $V_{CC(UVL)}$, then the iW1788 goes to shut-down. At this time the ENABLE signal becomes low, the depletion mode N-FET turns on, and the V_{CC} capacitor begins to charge up again towards the start-up threshold to initiate a new soft-start process.

In applications where the active start-up is not needed, the start-up resistor can be directly connected to the V_{CC} pin without using the active start-up device, and the ASU pin can be left unconnected.

9.3 Understanding Primary Feedback

Figure 9.2 illustrates a simplified flyback converter. When the switch Q1 conducts during $t_{ON}(t)$, the current $i_g(t)$ is directly drawn from rectified sinusoid $v_g(t)$. The energy $E_g(t)$ is stored in the magnetizing inductance L_M. The rectifying diode D1 is reversely-biased and the load current I_O is supplied by the secondary capacitor C_O. When Q1 turns off, D1 conducts and the stored energy $E_g(t)$ is delivered to the output.

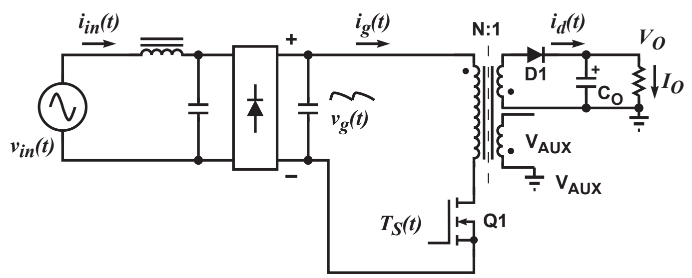


Figure 9.2: Simplified Flyback Converter

In order to tightly regulate the output voltage, the information about the output voltage and load current needs to be accurately sensed. In the DCM flyback converter, this information can be read via the auxiliary winding or the primary magnetizing inductance (L_M). During the Q1 on-time, the load current is supplied from the output filter capacitor C_O. The voltage across L_M is $v_g(t)$, assuming the voltage dropped across Q1 is zero. The current in Q1 ramps up linearly at a rate of:

$$\frac{di_g(t)}{dt} = \frac{v_g(t)}{L_M} \tag{9.1}$$

At the end of on-time, the current has ramped up to:

$$i_{g\_peak}(t) = \frac{v_g(t) \times t_{ON}}{L_M} \tag{9.2}$$

This current represents a stored energy of:

$$E_g = \frac{L_M}{2} \times i_{g\_peak}(t)^2 \tag{9.3}$$

When Q1 turns off at t_O, $i_g(t)$ in L_M forces a reversal of polarities on all windings. Ignoring the communication-time caused by the leakage inductance L_K at the instant of turn-off t_O, the primary current transfers to the secondary at a peak amplitude of:

$$i_d(t) = \frac{N_P}{N_S} \times i_{g\_peak}(t) \qquad (9.4)$$

Assuming the secondary winding is master, and the auxiliary winding is slave,

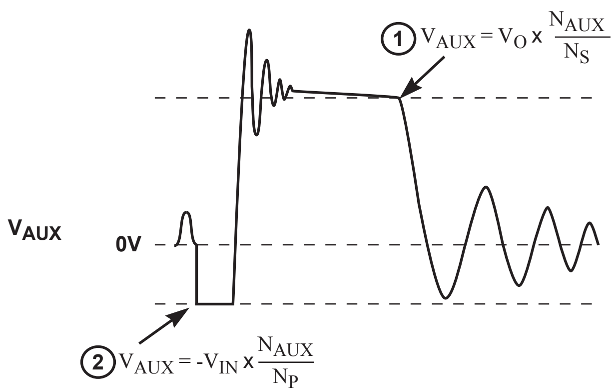


Figure 9.3: Auxiliary Voltage Waveforms

The auxiliary voltage is given by:

$$V_{AUX} = \frac{N_{AUX}}{N_S}(V_O + \Delta V) \qquad (9.5)$$

and reflects the output voltage as shown in Figure 9.3.

The voltage at the load differs from the secondary voltage by a diode drop and IR losses. Thus, if the secondary voltage is always read at a constant secondary current, the difference between the output voltage and the secondary voltage is a fixed ΔV. Furthermore, if the voltage can be read when the secondary current is small, ΔV is also small. With the iW1788, ΔV can be ignored.

The real-time waveform analyzer in the iW1788 reads this information cycle by cycle. The device then generates a feedback voltage VFB. The VFB signal precisely represents the output voltage under most conditions and is used to regulate the output voltage.

9.4 Constant Voltage Operation

After soft-start has been completed, the digital control block measures the output conditions. It determines output power levels and adjusts the control system according to a light load or heavy load. If this is in the normal range, the device operates in the Constant Voltage (CV) mode, and changes the pulse width (t_{ON}) and off time (t_{OFF}) in order to meet the output voltage regulation requirements.

If no voltage is detected on V_{SENSE} it is assumed that the auxiliary winding of the transformer is either open or shorted and the iW1788 shuts down.

9.5 Current Limit and Constant Current Operation

The constant current (CC) mode is useful in battery charging applications. During this mode of operation the iW1788 regulates the output current at a constant level regardless of the output voltage, while avoiding continuous conduction mode. To achieve this regulation the iW1788 senses the load current indirectly through the primary current, detected by the I_{SENSE} pin via a resistor from the BJT emitter to ground.

The constant current limit is set as a function of R_{SENSE} and the turns ratio of the transformer (N), with a correction term for the transformer efficiency (η_x) and is defined by equation 9.6. R_{SENSE} is calculated assuming a 5V output and 1.65A output current.

$$I_{CC\_LIMIT} = 0.225 \times \frac{N}{R_{SENSE}} \times \eta_x \qquad (9.6)$$

The iW1788 monitors the output voltage, and shuts down the system when the detected output voltage is lower than the internally programmed 2.5V constant currrent (CC) shutdown threshold.

For example, lets consider a 5V/1A charger design, if the cable resistance is around 150mΩ the voltage drop cross the cable is around 150mV under both the CV mode at full load and CC mode conditions. If CDC Comp is zero, at CV full load, the voltage at the PCB end is around 5V, and the voltage at the cable end is around 4.85V. Then the CC shutdown occurs when the voltage at the PCB end decreases to 2.5V. Without any cable compensation, and with the iW1788's internally fixed 2.5V CC shutdown voltage, the voltage at the end of cable is 2.35V when shutdown occurs. Normally a product option with CDC is needed in this design in order to achieve a desirable voltage regulation at CV mode, e.g., the CDC Comp production option is selected as 150mV. Then at CV full load, the voltage at the PCB end is around 5.15V, and the voltage at the cable end is around 5V.

Correspondingly the CC shutdown occurs when the voltage at the PCB end decreases to 2.65V, and the voltage at the cable end deceases to 2.5V.

When operating in the CC mode, with the decrease of equivalent load resistance or battery voltage, both the output voltage and V_{CC} decrease. Once the V_{CC} voltage is below UVLO threshold, the iW1788 shuts down (see Section 9.10).

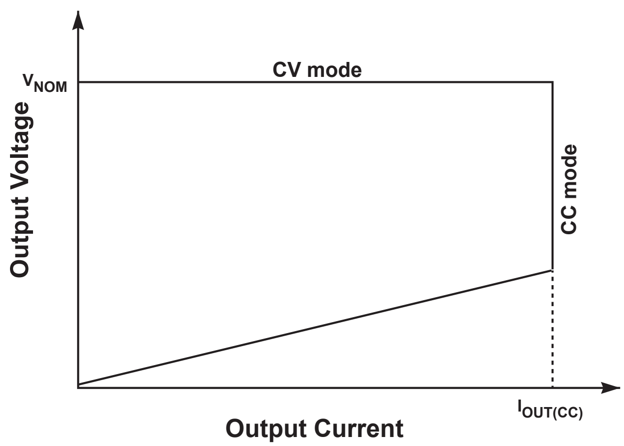


Figure 9.4: Power Envelope

9.6 Multi-Mode PWM/PFM Control and Quasi-Resonant Switching

The iW1788 uses a proprietary adaptive multi-mode PWM / PFM control to dramatically improve the light-load efficiency and the overall average efficiency.

During the constant voltage (CV) operation, the iW1788 normally operates in a pulse-width-modulation (PWM) mode in heavy load conditions. In the PWM mode, the switching frequency keeps around constant. As the output load I_{OUT} is reduced, the on-time t_{ON} is decreased, and the controller adaptively transitions to a pulse-frequency-modulation (PFM) mode. In the PFM mode, the MOSFET is turned on for a set duration under a given instantly-rectified AC input voltage, but its period is modulated by the load current. With a decreasing load current, the period increases and thus the switching frequency decreases.

When the switching frequency approaches the human ear audio band, the iW1788 transitions to a second level of PWM mode, namely the Deep PWM mode (DPWM). In the DPWM mode, the switching frequency keeps around 22kHz in order to avoid audible noise. As the load current is further reduced, the iW1788 transitions to a second level of PFM mode, namely the Deep PFM mode (DPFM), which can reduce the switching frequency to a very low level. Although the switching frequency drops across the audible frequency range during the DPFM mode, the output current in the power converter has reduced to an insignificant level in the DPWM mode before transitioning to the DPFM mode. Therefore, the power converter practically produces no audible noise, while achieving high efficiency across various load conditions.

As the load current reduces to very low or no-load condition, the iW1788 transitions from the DPFM to the third level of PWM mode, namely the Deep-Deep PWM mode (DDPWM), in which the switching frequency is fixed at around 2.1kHz.

The iW1788 also incorporates a unique proprietary quasi-resonant switching scheme that achieves valley-mode turn-on for every PWM/PFM switching cycle, in all PFM and PWM modes and in both CV and CC operations. This unique feature greatly reduces the switching loss and dv/dt across the entire operating range of the power supply. Due to the nature of quasi-resonant switching, the actual switching frequency can vary slightly cycle by cycle, providing the additional benefit of reducing EMI. These innovative digital control architecture and algorithms enable the iW1788 to achieve the highest overall efficiency and lowest EMI, without causing audible noise over entire operating range.

9.7 Less Than 30mW No-Load Power with Fast Load Transient Response

The iW1788 features a distinctive DDPWM control in no-load conditions to help achieve ultra-low no-load power consumption (< 30mW for typical 15W applications) and meanwhile to ensure fast dynamic load response. The power supply system designs including the pre-load resistor selection should ensure the power supply can operate in the DDPWM mode under the steady-state no-load condition. If the pre-load resistor is too small, the no-load power consumption increases; on the other hand, if it is too large, the output voltage may increase and even cause over-voltage since the switching frequency is fixed at around 2.1kHz. For typical designs, the pre-load resistor is in the range of 8kΩ to 10kΩ.

In addition to using pre-load resistor, the iW1788 employs a few other features to bring down no-load power consumption. First, the iW1788 implements an intelligent low-power management technique that achieves ultra-low chip operating current at no-load, typically less than 350μA. Second, a low UVLO threshold of 6.5V (typical) enables the power supply system design to have a low V_{CC} voltage at the no-load operation in order to minimize the no-load power. In addition, the active start-up scheme with depletion mode N-FET eliminates the start-up resistor power consumption after the ENABLE signal becomes active. These features combined ensure the lowest system cost power supplies built with the iW1788 can achieve less than 30 mW no-load power consumption at $230V_{AC}$ input, and very tight constant voltage and constant current regulation over the entire operating range in typical 15W adapter/charger applications.

While achieving ultra-low no-load power consumption, the iW1788 implements innovative proprietary digital control technology to intelligently detect any load transient events, and achieve fast dynamic load response for both one-time and repetitive load transients. In particular, for load transients that are demanded in some applications from no-load to full-load, the iW1788 can still maintain a fast enough response to meet the most stringent requirements, with the no-load operating frequency designed at around 2.1kHz.

9.8 Variable Frequency Operation Mode

In each of the switching cycles, the falling edge of V_{SENSE} is checked. If the falling edge of V_{SENSE} is not detected, the off-time is extended until the falling edge of V_{SENSE} is detected. The maximum allowed transformer reset time is 125μs. When the transformer reset time reaches 125μs, the iW1788 shuts off.

9.9 Internal Loop Compensation

The iW1788 incorporates an internal Digital Error Amplifier with no requirement for external loop compensation. For a typical power supply design, the loop stability is guaranteed to provide at least 45 degrees of phase margin and -20dB of gain margin.

9.10 Voltage Protection Features

The secondary maximum output DC voltage is limited by the iW1788. When the V_{SENSE} signal exceeds the output OVP threshold at point 1 indicated in Figure 9.3, the iW1788 shuts down.

The iW1788 protects against input line under-voltage by setting a maximum t_{ON} time. Since output power is proportional to the squared V_{IN} t_{ON} product, then for a given output power, as V_{IN} decreases the t_{ON} increases. Thus by knowing when the maximum t_{ON} time occurs the iW1788 detects that the minimum V_{IN} is reached, and shuts down. The maximum t_{ON} limit is set to 15.5μs. Also, the iW1788 monitors the voltage on the V_{CC} pin and when the voltage on this pin is below UVLO threshold the IC shuts down immediately.

When any of these faults are met the IC remains biased to discharge the V_{CC} supply. Once V_{CC} drops below UVLO threshold, the controller resets itself and then initiates a new soft-start cycle. The controller continues attempting start-up until the fault condition is removed.

9.11 PCL, OCP and SRS Protection

Peak-current limit (PCL), over-current protection (OCP) and sense-resistor-short protection (SRSP) are features built into the iW1788. With the I_{SENSE} pin the iW1788 is able to monitor the peak primary current. This allows for cycle-by-cycle peak current control and limit. When the peak primary current multiplied by the I_{SENSE} resistor is greater than 1.1V, over-current is detected and the IC immediately turns off the gate driver until the next cycle. The output driver sends out a switching pulse in the following cycle, and the switching pulse continues if the OCP threshold is not reached; or, the switching pulse turns off again if the OCP threshold is reached. If the OCP occurs for several consecutive switching cycles, the iW1788 shuts down.

If the I_{SENSE} resistor is shorted, there is a potential danger that over-current condition may not be detected. Thus, the IC is designed to detect this sense-resistor-short fault after start-up and shut down immediately. The V_{CC} is discharged since the IC remains biased. Once V_{CC} drops below the UVLO threshold, the controller resets itself and then initiates a new soft-start cycle. The controller continues attempting to start up, but does not fully start up until the fault condition is removed.

9.12 CDC Configuration

The iW1788 incorporates an innovative approach to allow users to configure cable drop compensation (CDC) externally. This configuration is only performed once at the beginning of start-up. It is completed after the initial OTP check but before the soft-start commences. During the CDC configuration, the internal digital control block senses the external resistance value between the CDC pin and ground, and then sets a corresponding CDC level to allow the device to compensate for IR drop in the secondary circuitry during normal operation.

Figure 3.1 shows a simple circuit to set CDC level by connecting a resistor from the CDC pin to ground. The iW1788 provides five levels of CDC configurations: 0, 75mV, 150mV, 300mV, and 450mV, which refer to 5V nominal output voltage. Table 9.1 below shows the resistance range for each of the five CDC levels. In practice, it is recommended to select resistance in the middle of the range wherever possible.

The “Cable Comp” specified in Table 9.1 refers to the voltage increment at PCB end from no-load to full-load conditions in the CV mode, with the assumption that the secondary diode voltage drop can be ignored at the point when the secondary voltage is sensed.

To calculate the amount of cable compensation needed, take the resistance of the cable and connector and multiply it by the maximum output current.

9.13 External OTP

The iW1788 can be configured to provide external over-temperature protection (OTP) by connecting a Negative-Temperature-Coefficient (NTC) resistor from SD/OTP pin to GND. Internally, a 100μA current source is injected to the SD/OTP pin, which generates a voltage proportional to the NTC resistance. At high ambient temperatures, the NTC resistance becomes low, which results in a low voltage at the SD/OTP pin. If the SD/OTP pin voltage drops below an internally-set threshold, then the OTP is triggered, and the iW1788 shuts down.

In the iW1788, the external OTP has a built-in hysteresis by having two thresholds. Before start-up, the OTP is triggered if the SD/OTP pin voltage is less than 1.2V; otherwise the device begins the CDC configuration (see Section 9.12), then followed by a normal soft-start process. During normal operation, the OTP threshold is switched to 1.0V, and the device only shuts down when the SD/OTP pin voltage is less than 1.0V.

During normal operation, if the voltage of the SD/OTP pin is below 1.0, then the OTP is triggered, and the device shuts down.

The SD/OTP and CDC pins can be configured to provide different types of applications. Figure 9.5 shows four basic configurations:

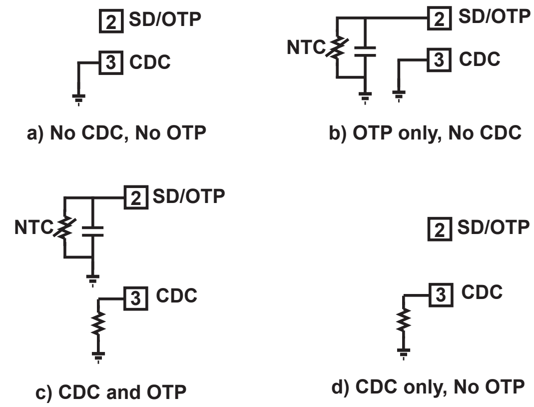


Figure 9.5: CDC and SD/OTP Pins Configurations

In Scheme (a), the CDC pin is directly connected to ground, which sets CDC level to be 1 (i.e. no CDC). On the other side, leaving the SD/OTP pin unconnected disables the OTP function.

In Scheme (b), CDC is set to level 1, as in Scheme (a) by grounding the CDC pin. An NTC resistor in paralleled with a capacitor enables the external OTP protection. Note this capacitor is only for decoupling purpose. Its capacitance needs to be less than 47pF; otherwise the voltage at this pin can cause a prolonged delay and incur unwanted behaviors.

In Scheme (c), a resistor from the CDC pin to ground allows for setting the desired CDC level. Similarly, the NTC resistor enables the external OTP, as it does in Scheme (b).

In Scheme (d), a resistor from the CDC pin to ground allows for setting the desired CDC level. On the other side, leaving the SD/OTP pin unconnected disables the OTP function.

Table 9.1: Recommended resistance range and corresponding CDC levels for 5V output

CDC Level	1	2	3	4	5
R_{CDC} Range (kΩ)	0 ~ 2.20	2.37 ~ 3.21	3.40 ~ 4.64	4.87 ~ 6.65	6.98 ~ X*
Cable Comp (mV)	0	75	150	300	450

** The resistance can be as high as 100kΩ, provided SD/OTP pin does not float, which causes device to shut down.*

9.14 Pump Express™ Plus Protocol

The iW1788 is another rapid charge device from Dialog, compatible with MediaTek's Pump Express Plus protocol, a complement to the standard Pump Express protocol for lower power applications, served by the iW1680. MediaTek's Pump Express Plus technology, established to improve charging times for smartphones and tablets in adapters, allows for output power capability up to 15W for larger capacity batteries and even faster charging times than the main Pump Express Protocol. Being compatible with Pump Express Plus means that the iW1788 can change its output voltage from its default 5V output state to as high as 12V or down to 3.6V in order to optimize battery charging, reducing charge time and helping to minimize cost. The iW1788 contains a core digital algorithm to interface with a Pump Express Plus-compatible device which sends commands to the iW1788 in order to change the output voltage of the power supply. The command string is detected via the Vbus pin of the USB connector, leaving the D+ and D- pins unused to send or receive these commands, improving the reliability of the adapter.

Command Strings

The output voltage is controlled via a simple command string that is generated by drawing pulses of current from the output and that current is detected at the I_{SENSE} pin by the PrimAccurate™ primary-side digital control block. The command string is comprised of two key elements, the programming code and a watchdog timer. The string is one of two mutually orthoganal patterns of current pulses that are detected on the I_{SENSE} pin. The I_{SENSE} pin detects a specific pattern based on a current amplitude and period. The logic high current level is any current above 250mA and the logic low current level is any current below 130mA. Figure 9.6 shows the basic command string to increase the output voltage. There is no initialization or handshaking protocol. The output starts at a default 5V when initially powered and stays at 5V until any command is received.

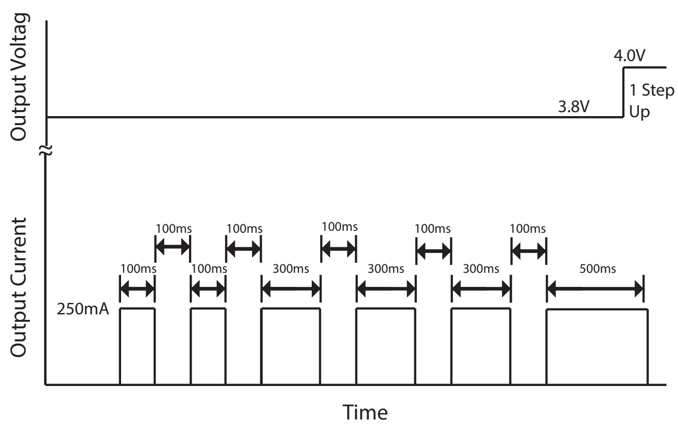


Figure 9.6: Increase Output Voltage Command

The current pulse train shown in Figure 9.7 represents the string to decrease the output voltage and increase the constant current limit. The user can apply the decrease commands, cycling through the voltages until reaching the final desired output voltage. The watchdog timer monitors the output and if the output current goes below the minimum low current level for programming (130mA) for 220ms or longer, the output automatically resets to 5V. This serves two functions, to act as a quick return to 5V and to determine if the adapter is unplugged from the mobile device.

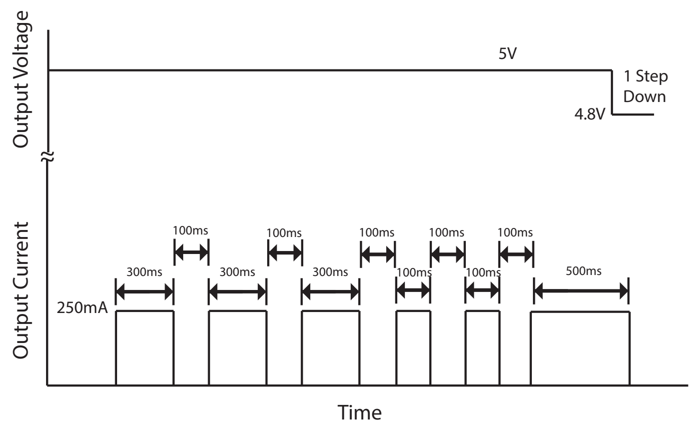


Figure 9.7: Command to Decrease Output Voltage

On the iW1788, the user can increase the voltage to 7V, 9V or 12V or decrease the voltage from 5V in fine 200mV steps down to a minimum of 3.6V. At any time, the user can return to the default 5.0V by removing the load from the output and waiting at least 220ms, at which time, the controller returns the output voltage to 5.0V. This is a shortcut in the event that the system needs to return quickly to 5V. In the event that the connector is disconnected when the output of the adapter is at a high voltage, an external discharge circuit is recommended to ensure that the output voltage returns quickly to 5V prior to reconnecting to the adapter. Figure 9.8 shows the state machine for the iW1788 output voltage.

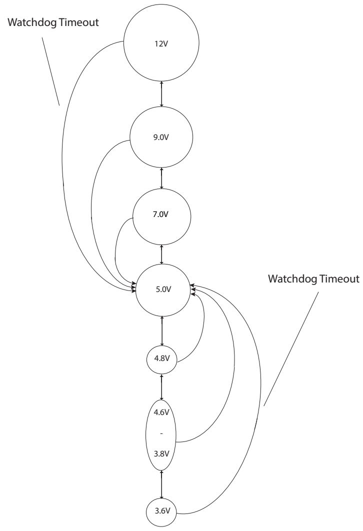


Figure 9.8: State Machine

Watchdog Timeout

The watchdog function primarily serves to detect if the adapter has been unplugged from the mobile device, subsequently resetting the output voltage back to the default 5V output voltage. Figure 9.9 depicts the watchdog functionality and how it is used. After two command strings, the output current stays below 130mA for more than 220ms and the output resets to its default 5V state. This guarantees that when the adapter is reconnected, it is always in its default state. And, it also guarantees that if the adapter is used with a non fast-charge-enabled mobile device, the output maintains its USB-compliant 5V output, making adapters using the iW1788 backwards-compatible with 5V USB standards. The messages used to control the output voltage are orthaganol and guarantee no practical possiblity of a false positive message, and they also ensure that the same adapter can be used for devices that offer the fast-charge capability and devices that do not.

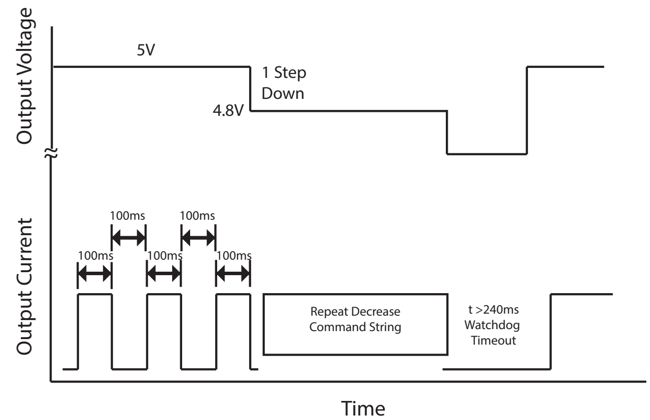


Figure 9.9: Watchdog Timeout

Power Limiting Function

The iW1788 allows for optimization of the output transformer by offering a constant power limit function, where the current limit changes with output voltage, permitting the designer to reduce the size of the output transformer compared to competitive solutions with a constant current limit across all voltages. Figure 9.10 shows the typical characteristics of the output current vs output voltage for the iW1788. The constant current limit is initially programmed using the formula shown in section 9.5 of the iW1788 datasheet. The main current limit should be programmed for the 5V default output setting and the digital controller modifies the current limit as the output voltage changes.

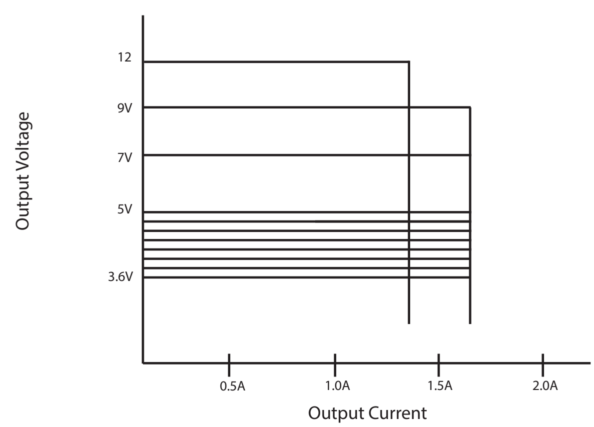


Figure 9.10: iW1788 Constant Current/Constant Voltage Curves

Test Mode

The iW1788 includes a test mode to allow the adapter manufacturer to quickly test the different voltage options at final electrical test. The timing diagram in Figure 9.11 shows the command that puts the device into test mode.

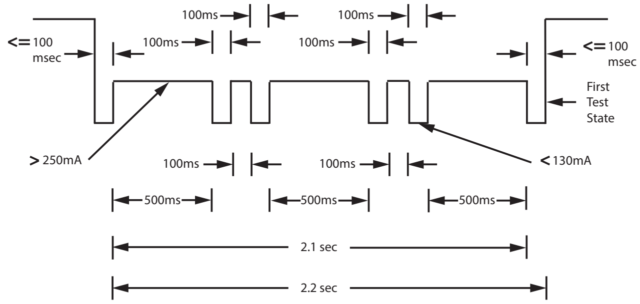


Figure 9.11: Command to Enable Adapter Test Mode

Once in test mode, the output can be quickly cycled through the different voltage steps as depicted in Figure 9.12.

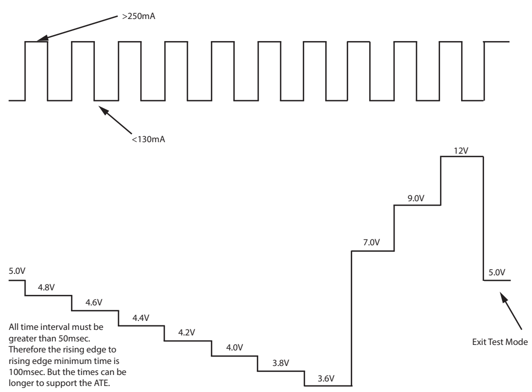


Figure 9.12: Command to Cycle Output Voltage During Test Mode

Once the output has been cycled through its full range of voltages, it automatically exits test mode and return to the default 5V output voltage setting. The suggested minimum test time to account for settling and to allow for an accurate voltage measurement is 100ms. The time can be longer depending upon the ATE used at final test.

Output Discharge Circuit

Such a wide output voltage range of 3.6V to 12V could result in a condition where the output voltage needs to quickly change from 12V to 5V. When the current drawn by the output drops below 100mA for more than 220ms, the controller's watchdog timeout circuit detects this and the output defaults back to 5V. This could be because the battery is now fully charged (or near full charge) or the cable has been disconnected. In the event of a disconnect event, the load goes away and the output needs to discharge quickly back to 5V to avoid an potential problems that could occur if the output voltage is not at 5V when reconnected to the mobile device. An additional circuit can be added to the output to ensure that transitions from high to low happen quickly. Figure 9.13 shows a very simple discharge circuit that is only active when the output needs to discharge. The remainder of the time, the discharge circuit is off, avoiding adding any static load to maintain the no-load power consumption of 30mW or below.

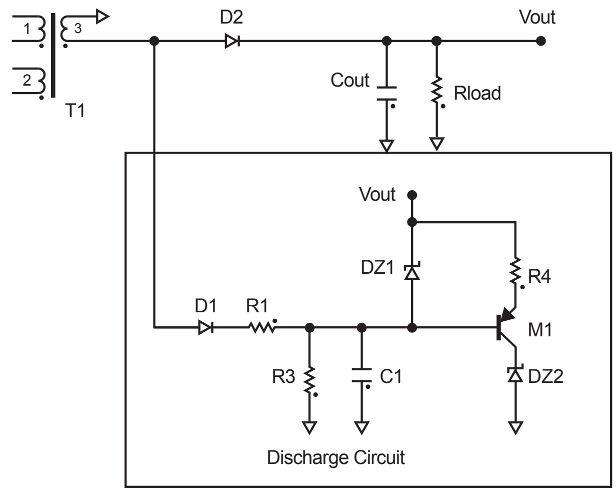


Figure 9.13: Output Discharge Circuit

When the output is at 12V and supplying current to the load, the output of the transformer is sending pulses of current through to the load. D1 and R1 peak detect the voltage off of the output of the transformer and C1 charges up to approximately the same voltage as the output voltage (see figure 9.16).

When the output current drops, the pulses from the transformer become smaller and smaller, allowing C1 to discharge through R3. When C1 discharges to a diode drop below the output voltage voltage, M1 turns on and conducts a maximum current established by R4 and DZ1. At the

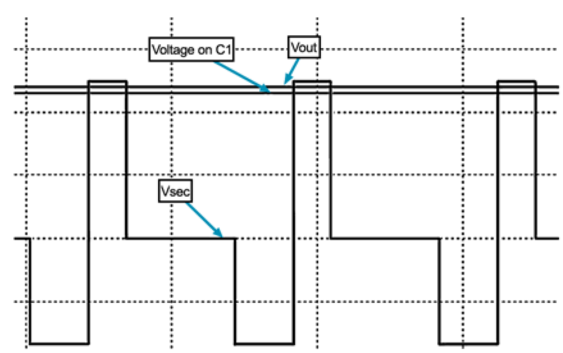


Figure 9.14: Discharge Circuit Waveform (a)

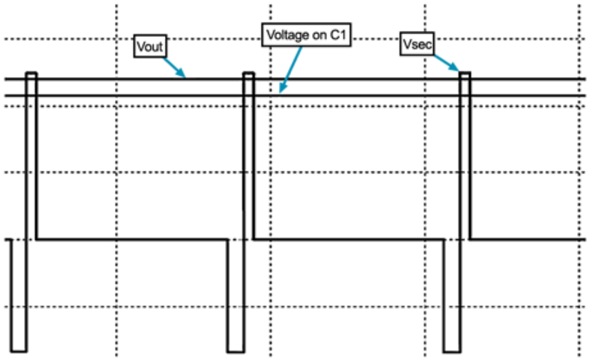


Figure 9.15: Discharge Circuit Waveform (b)

same time, the controller detects the disconnect condition and resets the default output voltage to 5V, reducing the pulses to the output even further, and current through M1 increases to its max limit set by R4 and DZ1. DZ2 sets the voltage at which the discharge circuit stops discharging the output. The voltage should be set slightly above the output voltage ensuring that during normal operation at 5V that the discharge circuit is not consuming any nominal power, allowing the controller to maintain its no-load power consumption levels.

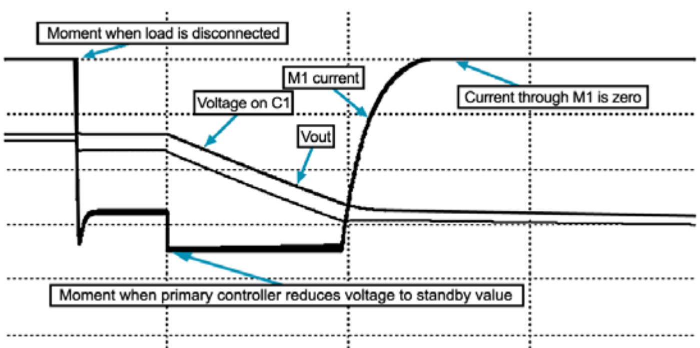
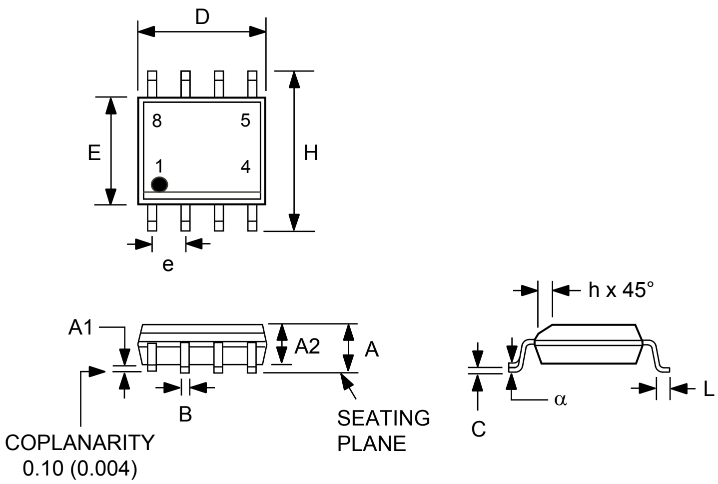


Figure 9.16: Output Voltage Waveforms - Discharge Circuit

10.0 Physical Dimensions

8-Lead Small Outline (SOIC) Package



Symbol	Inches		Millimeters	
	MIN	MAX	MIN	MAX
A	0.053	0.069	1.35	1.75
A1	0.0040	0.010	0.10	0.25
A2	0.049	0.059	1.25	1.50
B	0.014	0.019	0.35	0.49
C	0.007	0.010	0.19	0.25
D	0.189	0.197	4.80	5.00
E	0.150	0.157	3.80	4.00
e	0.050 BSC		1.27 BSC	
H	0.228	0.244	5.80	6.20
h	0.10	0.020	0.25	0.50
L	0.016	0.049	0.4	1.25
α	0°	8°		

Compliant to JEDEC Standard MS12F

Controlling dimensions are in inches; millimeter dimensions are for reference only

This product is RoHS compliant and Halide free.

Soldering Temperature Resistance:
- [a] Package is IPC/JEDEC Std 020D moisture sensitivity level 1
- [b] Package exceeds JEDEC Std No. 22-A111 for solder immersion resistance; package can withstand 10 s immersion < 260˚C

Dimension D does not include mold flash, protrusions or gate burrs. Mold flash, protrusions or gate burrs shall not exceed 0.15 mm per end. Dimension E1 does not include interlead flash or protrusion. Interlead flash or protrusion shall not exceed 0.25 mm per side.

The package top may be smaller than the package bottom. Dimensions D and E1 are determined at the outermost extremes of the plastic body exclusive of mold flash, tie bar burrs, gate burrs and interlead flash, but including any mismatch between the top and bottom of the plastic body.

11.0 Ordering Information

Part Number	Options	Package	Description
iW1788-26	15W, 12V Max Output Voltage	SOIC-8	Tape & Reel[1]

Note 1: Tape & Reel packing quantity is 2,500/reel. Minimum ordering quantity is 2,500.

High Power Pump Express™ Plus-Compatible Digital PWM AC/DC Controller

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