High Efficiency 6-Channel Charge-Pump LED Driver

GENERAL DESCRIPTION

The ft3356 is a low noise, high efficiency 6-channel charge-pump LED driver that uses a quad-mode load switch: pass-through (1X), fractional (1.33X/1.5X), or doubling (2X) conversion to maximize efficiency for white LED applications. The ft3356 is capable of driving 6 LED channels from a 2.7V to 5.5V input. The 6 current sinks can operate individually or in parallel for driving higher current LEDs. It requires a minimum number of external components (1μF flying capacitors and two small 1μF capacitors at VIN and VOUT), which makes the device ideal for use in battery-powered portable applications.

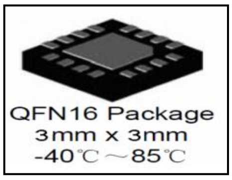
The ft3356 uses a single-wire pulse interface to enable, disable, and set current for each LED channel with eight settings (20mA down to 50μA) including main and sub-display group control. Each channel output is short-circuit protected. Soft-start circuitry prevents excessive inrush current during start-up. A low power shutdown mode disconnects the load from VIN and reduces quiescent current to less than 1μA. It is available in QFN3x3-16L package.

FEATURES

- VIN range: 2.7V to 5.5V
- Fully programmable current with single-wire
  - Eight-step current: 20mA to 50μA
  - Individual main-sub group control
- Quad-mode charge-pump: 1X, 1.33X, 1.5X, 2X
- High efficiency up to 92%
- Drives up to six LED channels
- Low input ripples in all modes
- Minimum number of external components
- Built-In short-circuit protection
- Soft-start function limiting inrush current
- Low shutdown current I_{SHDN} <1μA
- Available in QFN3X3-16L package

APPLICATIONS

- LCD display backlight
- Cellular phone
- Digital still camera
- Handheld devices



APPLICATION CIRCUIT

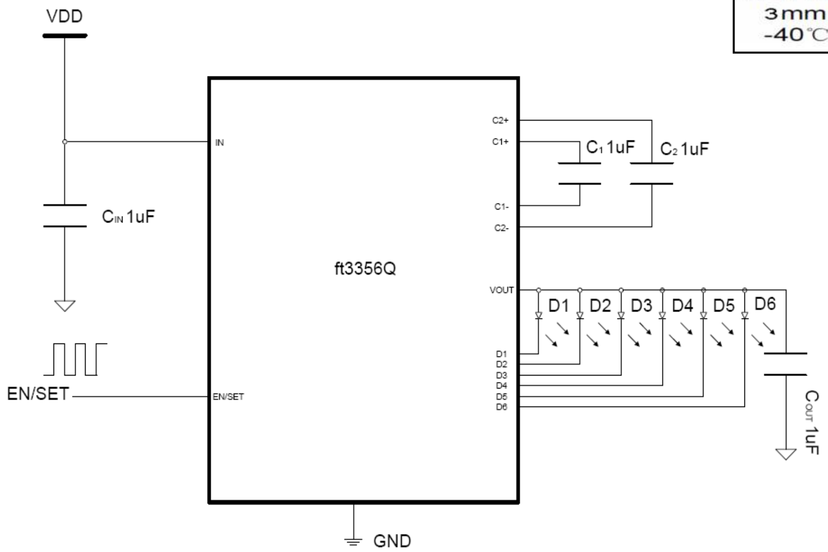
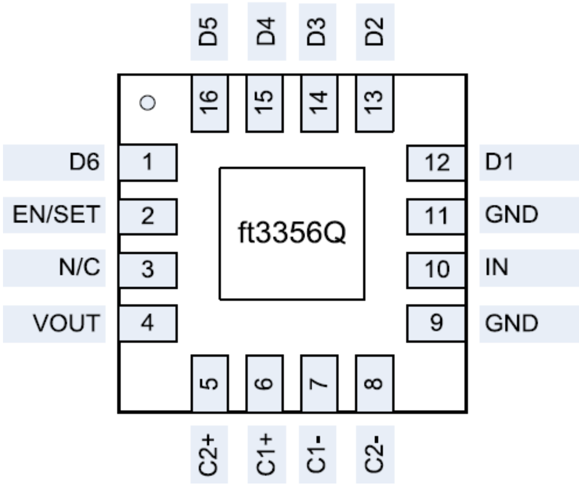


Figure 1: Typical Application Circuit

PIN CONFIGURATION AND DESCRIPTION



SYMBOL	PIN #	DESCRIPTION
D6	1	Current sink input #6.
EN/SET	2	Single-wire pulse-programming interface control pin.
N/C	3	No connection.
VOUT	4	Charge pump output to drive load circuit. Requires 1μF capacitor connected between this pin and ground.
C2+	5	Flying capacitor 2 positive terminal. Connect a 1μF capacitor between C2+ and C2-.
C1+	6	Flying capacitor 1 positive terminal. Connect a 1μF capacitor between C1+ and C1-.
C1-	7	Flying capacitor 1 negative terminal.
C2-	8	Flying capacitor 2 negative terminal.
GND	9/11	Ground
IN	10	Input power supply. Requires 1μF capacitor connected between this pin and ground.
D1	12	Current sink input #1.
D2	13	Current sink input #2.
D3	14	Current sink input #3.
D4	15	Current sink input #4.
D5	16	Current sink input #5.
	EP	Exposed paddle (bottom); connect to GND directly beneath package.

ORDERING INFORMATION

PART NUMBER	TEMPERATURE RANGE	PACKAGE
ft3356Q	-40°C to +85°C	QFN3X3-16L

ABSOLUTE MAXIMUM RATINGS

PARAMETER	VALUE
Input voltage	-0.3V to 6.0V
EN/SET to GND voltage	-0.3V to VIN+0.3V
Maximum DC output current	180mA
Operating junction temperature range	-50°C to 150°C
Maximum soldering temperature (10 sec)	300°C

Note: Stresses beyond those listed under absolute maximun ratings may cause permanent damage to the device. These are stress ratings only,and functional operation of the device at these or any other conditions beyond those indicated under recommended operating conditions is not implied.Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

THERMAL INFORMATION

PARAMETER	DESCRIPTION	VALUE	UNIT
PD	Maximum power dissipation	2.0	W
θ_{JA}	Maximum thermal resistance	128.4	°C/W

RECOMMENDED OPERATING CONDITIONS

PARAMETER	MIN	TYP	MAX	UNIT
VIN	2.7		5.5	V
Ambient temperature range	-40		85	°C
ILED per LED pin	0		20	mA

ELECTRICAL CHARACTERISTICS[1]

C_{IN} = C_{OUT} = C_1 = C_2 = 1.0μF; T_A = -40°C to +85°C, unless otherwise noted. Typical values are for T_A = 25°C, V_{IN} = 3.6V.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
INPUT POWER SUPPLY						
IQ	Quiescent current	1X Mode, 3.0≤VIN≤5.5, Active, No Load Current		1.0		mA
		1.33X Mode, 3.0≤VIN≤5.5, Active, No Load Current		1.7		mA
		1.5X Mode, 3.0≤VIN≤5.5, Active, No Load Current		2.2		mA
		2X Mode, 3.0≤VIN≤5.5, Active, No Load Current		2.4		mA
ISHDN	Shutdown current	EN/SET = 0			1	μA
IACC	ISINK average current accuracy	ISET = 20mA	18	20	22	mA
IMatch	Current matching between any two current sink inputs[2,3]	(ILED-ILEDAVG)/ILED		5		%
LEDTH	1X to 1.5X ,1.33X to 1.5X or 1.5X to 2X transition threshold at any ISINK pin			150		mV
ISC_MAX	Output short circuit current limit	VOUT < 0.5V		80		mA
VUVLO	Under voltage lockout (UVLO threshold)		1.6	1.8	2.0	V
CHARGE PUMP SECTION						
TSS	Soft-start time			100		μs
FOSC	Charge pump frequency	1.33x and 2x mode	0.8	1.0	1.3	MHz
		1.5x mode	1.0	1.3	1.6	
EN/SET						
REN/SET	Internal pull-down resistor			330		kΩ
VEN(L)	Enable threshold LOW	VIN=2.7V			0.3	V
VEN(H)	Enable threshold HIGH	VIN=5.5V	1.5			V
TSD	Thermal shutdown			150		°C
RECOMMENDED EN/SET TIMING						
TLO	EN/SET program low time		0.3		75	us
THI	EN/SET program high time		50			ns
TOFF	EN/SET low time to shutdown		100		1000	us

Notes:

1. The ft3356Q is guaranteed to meet performance specifications over the -40°C to +85°C operating temperature range and is assured by design, characterization, and correlation with statistical process controls.

2. Current matching is defined as the deviation of any sink current from the average of all active channels.

3. Specification applies only to the quad-mode charge pump.

TYPICAL CHARACTERISTICS

V_{IN} = 3.6V, I_{OUT} = 120mA (6 LEDs at 20mA), C_{IN} = C_{OUT} = C_1 = C_2 = 1μF, T_A = 25°C unless otherwise specified.

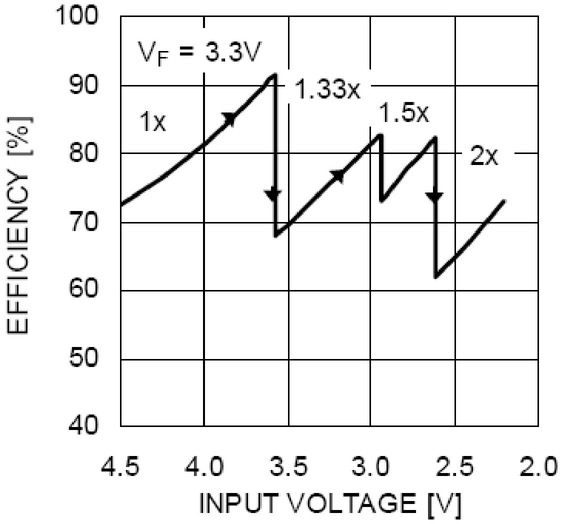


Figure 2: Efficiency vs. Input Voltage

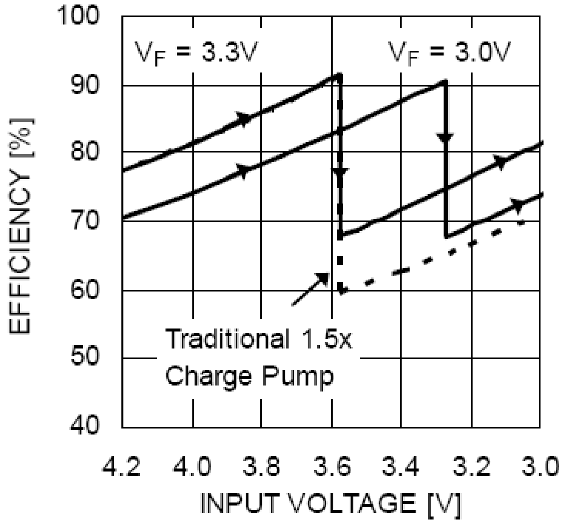


Figure 3: Efficiency vs. Input Voltage

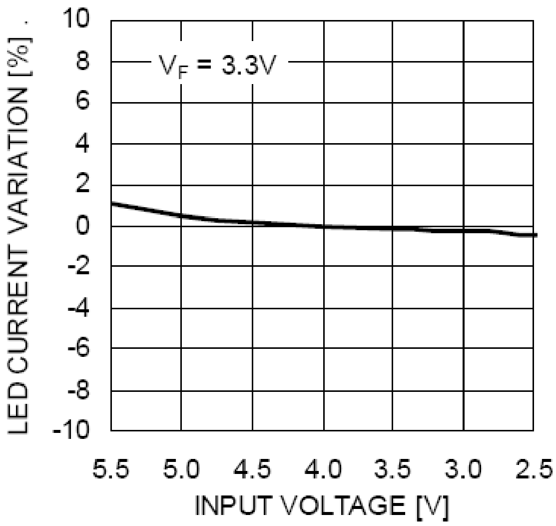


Figure 4: LED Current Change vs. Input Voltage

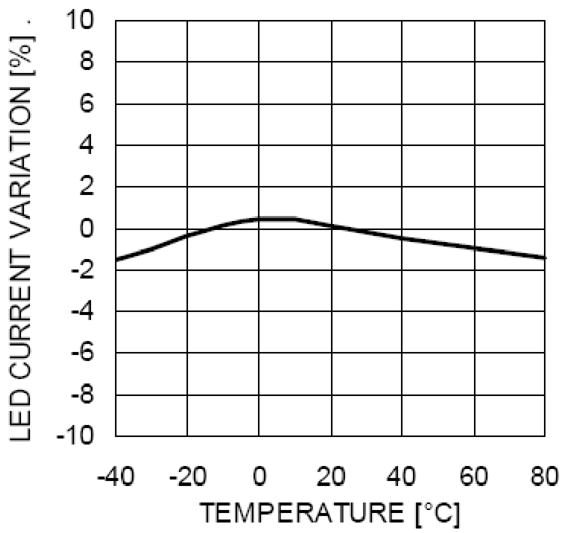


Figure 5: LED Current Change vs. Temperature

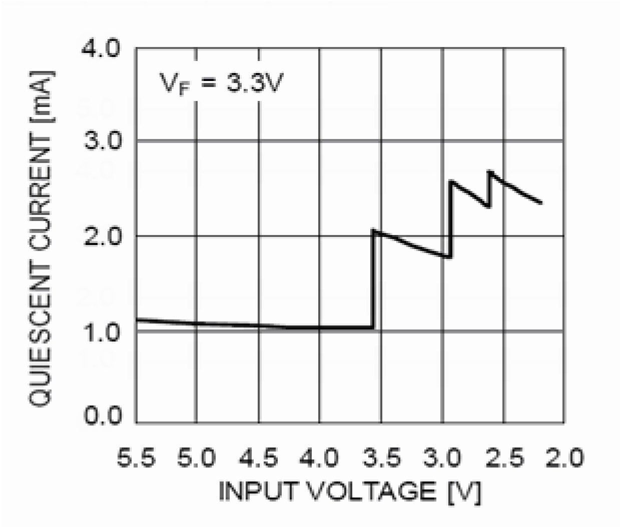


Figure 6: Quiescent Current vs. Input Voltage

TYPICAL CHARACTERISTICS

V_{IN} = 3.6V, I_{OUT} = 120mA (6 LEDs at 20mA), C_{IN} = C_{OUT} = C_1 = C_2 = 1μF, T_A = 25°C unless otherwise specified.

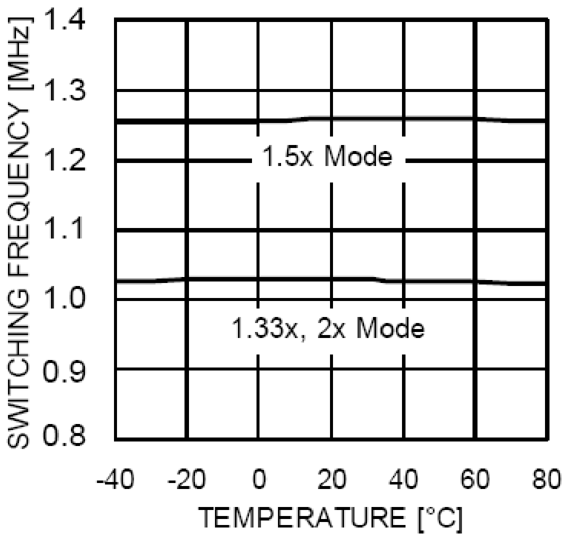


Figure 7: Switching Frequency vs. Temperature

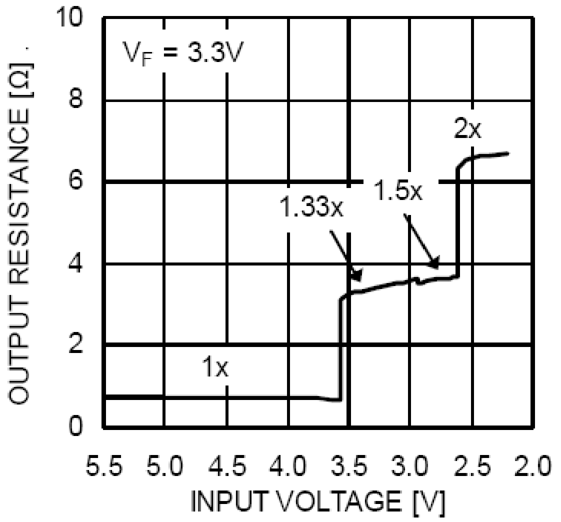


Figure 8: Output Resistance vs. Input Voltage

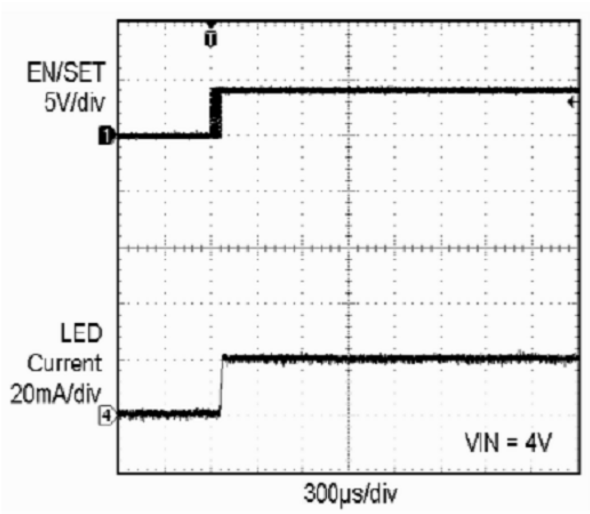


Figure 9: Power Up in 1 x Mode

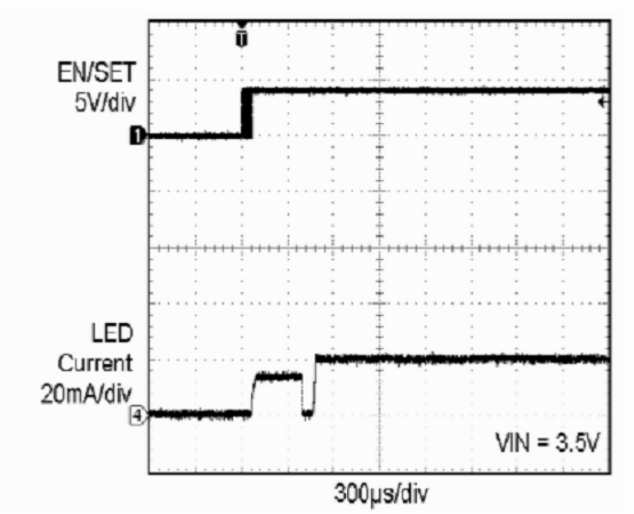


Figure 10: Power Up in 1.33 x Mode

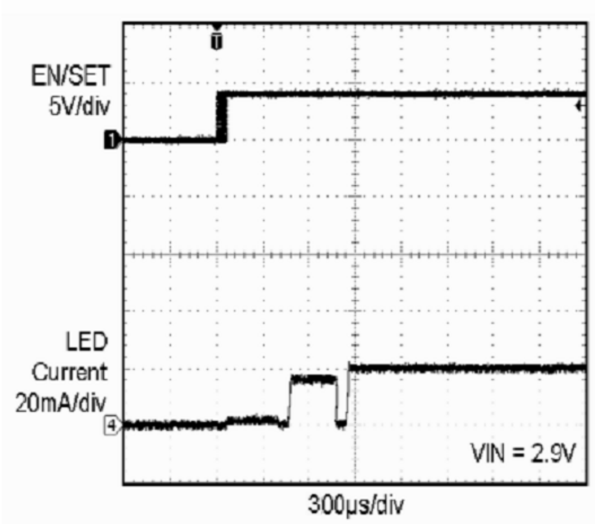


Figure 11: Power Up in 1.5 x Mode

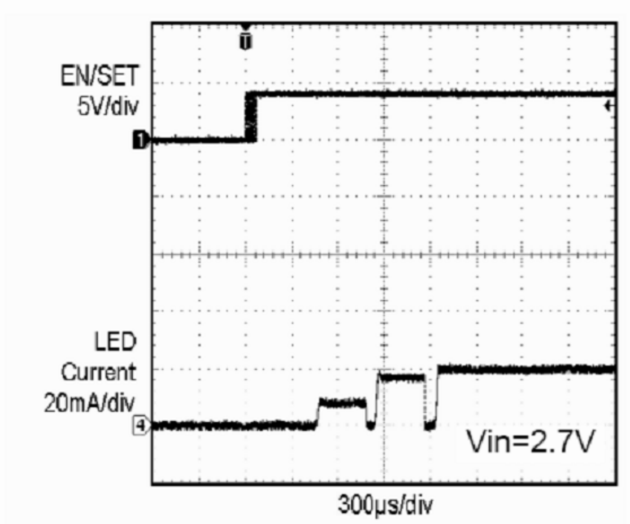


Figure 12: Power Up in 2 x Mode

TYPICAL CHARACTERISTICS

V_{IN} = 3.6V, I_{OUT} = 120mA (6 LEDs at 20mA), C_{IN} = C_{OUT} = C_1 = C_2 = 1μF, T_A = 25°C unless otherwise specified.

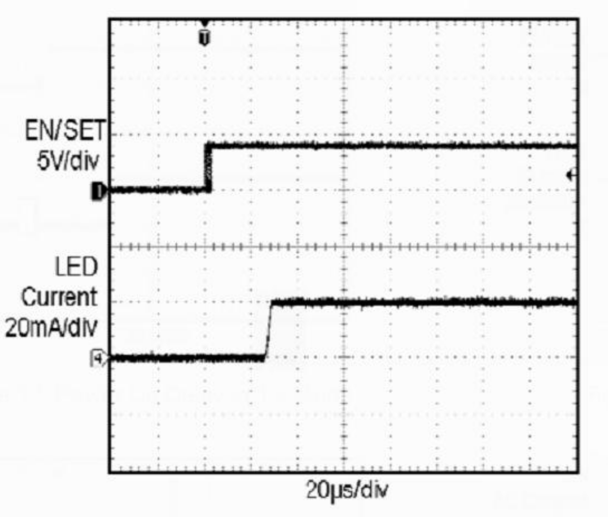


Figure 13: Power Up Delay in 1 x Mode

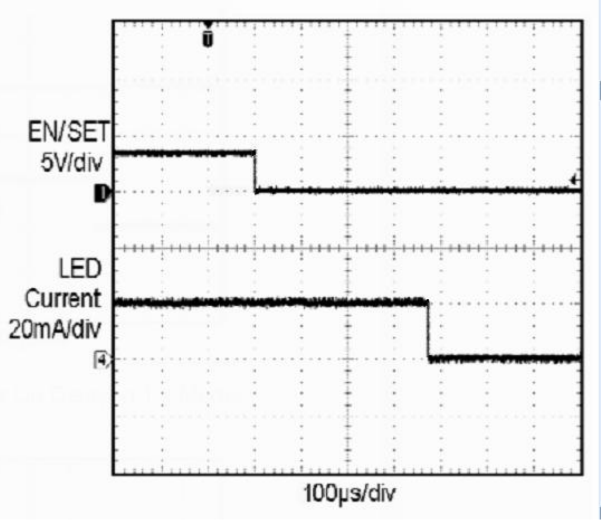


Figure 14: Power Down Delay in 1 x Mode

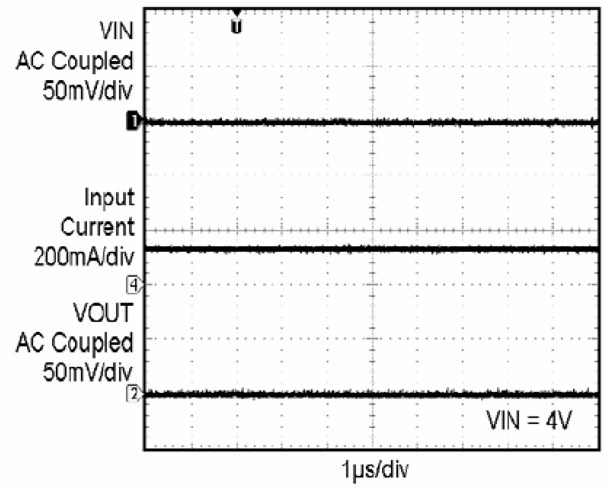


Figure 15: Operating Waveforms in 1 x Mode

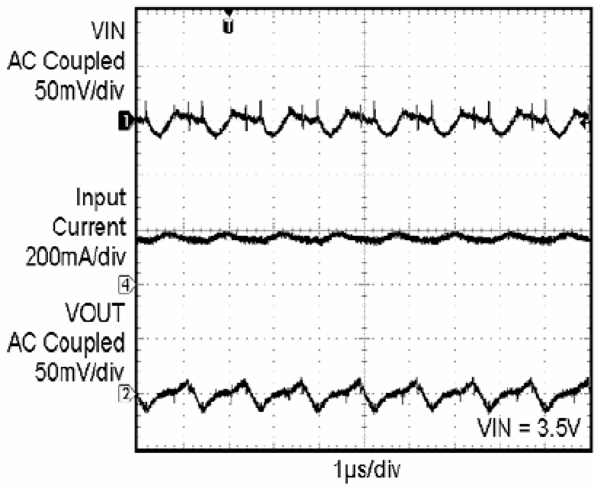


Figure 16: Switching Waveforms in 1.33 x Mode

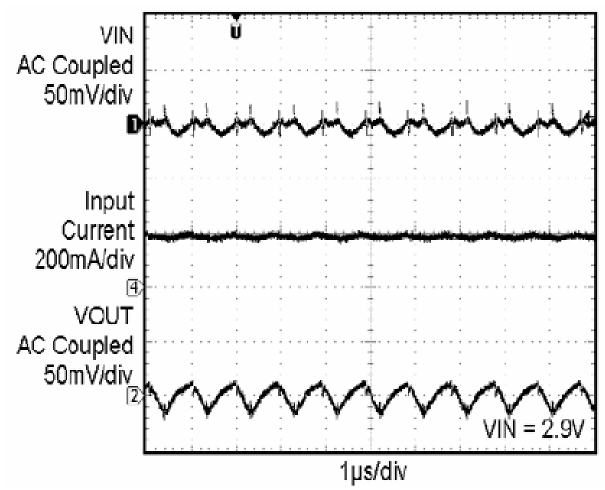


Figure 17: Switching Waveforms in 1.5 x Mode

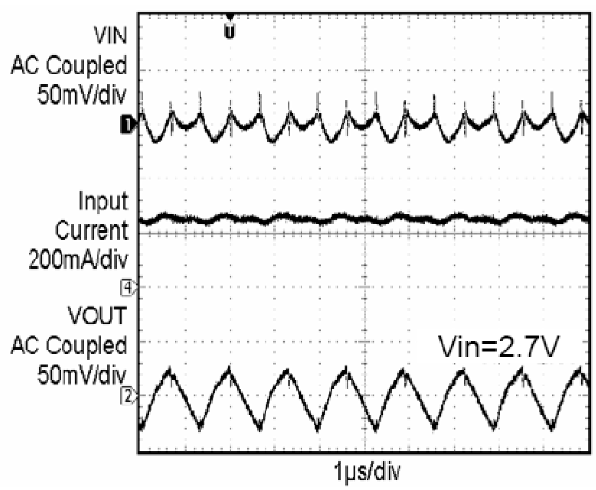


Figure 18: Switching Waveforms in 2 x Mode

FUNCTIONAL BLOCK DIAGRAM

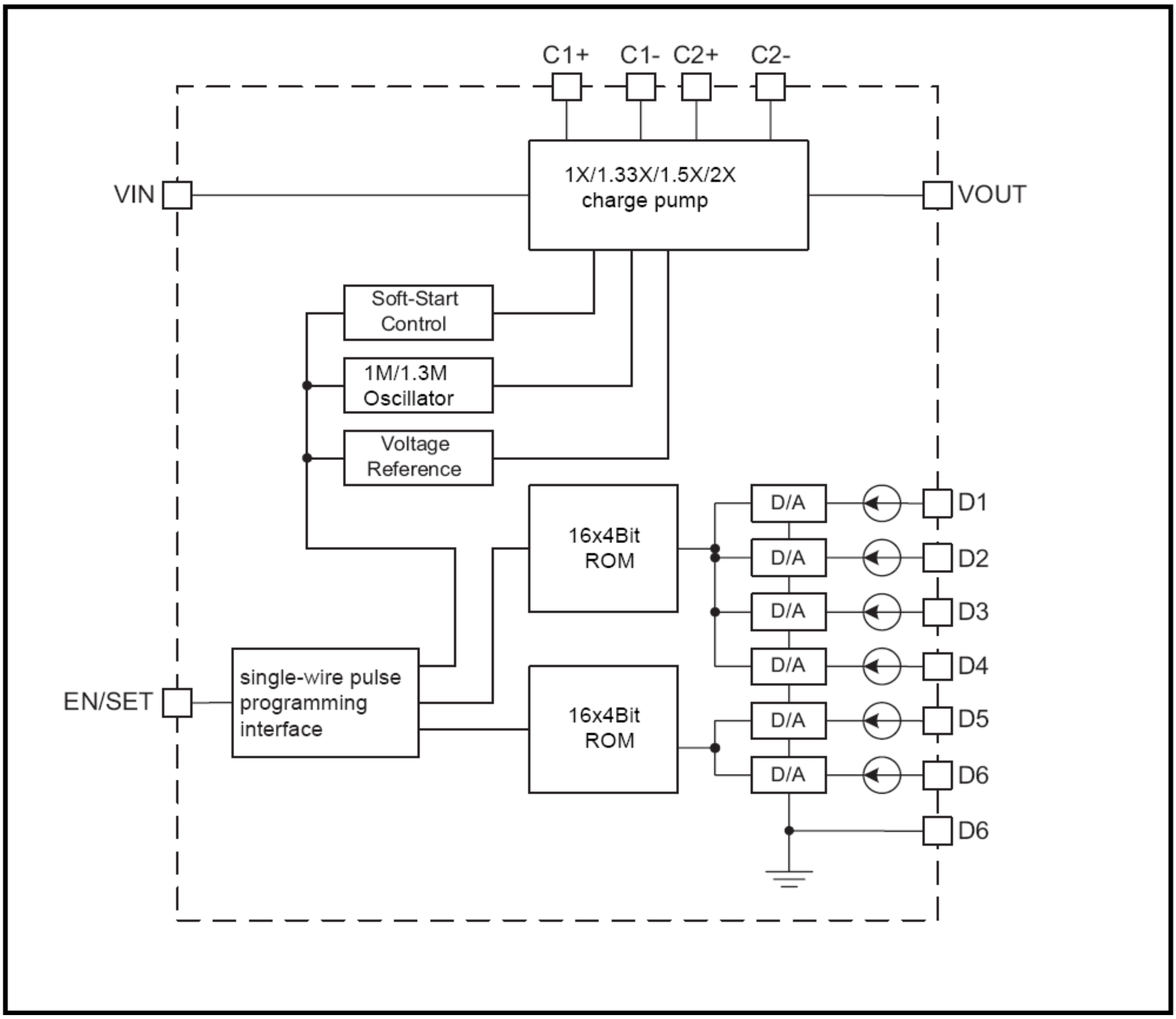


Figure 19: Functional Block Diagram

FUNCTIONAL DESCRIPTION

The ft3356 is a quad-mode load switch (1X) and high efficiency (1.33X/1.5X/2X) charge pump device intended for white LED backlight applications. To maximize power conversion efficiency, an internal sensing circuit monitors the voltage required on each constant current sink input and sets the load switch and charge pump modes based on the input battery voltage and the current sink input voltage. As the battery discharges over time, the ft3356 charge pump is enabled when any of the used current sink inputs near dropout. The charge pump initially starts in 1.33X mode. If the charge pump output drops enough for any current source output to become close to dropout, the charge pump will automatically transition to 1.5X or 2X mode. The ft3356 requires only four external components: two 1μF ceramic capacitors for the charge pump flying capacitors (C1 and C2), one 1μF ceramic input capacitor (CIN), and one 0.33μF to 1μF ceramic charge pump output capacitor (COUT). The six constant current sink inputs (D1 to D6) can drive six individual LEDs with a maximum current of 20mA each. The unused sink inputs must be connected to VOUT, otherwise the part will operate only in 2X charge pump mode. A single-wire pulse-programming interface enables the ft3356 and sets the current sink magnitudes. The single-wire interface addressing allows independent control of two groups of current sink input: D1-D4 and D5-D6.

CONSTANT CURRENT OUTPUT LEVEL SETTINGS

The constant current sink levels for D1 to D6 are set via the serial interface. No PWM (pulse width modulation) or additional control circuitry are needed to control LED brightness. This feature greatly reduces the burden on a microcontroller or system IC to manage LED or display brightness, allowing the user to "set it and forget it." With its high-speed serial interface (up to 1MHz data rate), the input sink current of the ft3356 can be changed successively to brighten or dim LEDs, giving the users real-time control of LED brightness. Because the inputs D1 to D6 are true independent constant current sinks, the voltage observed on any single given input will be determined by the actual forward voltage (VF) for the LED being driven.

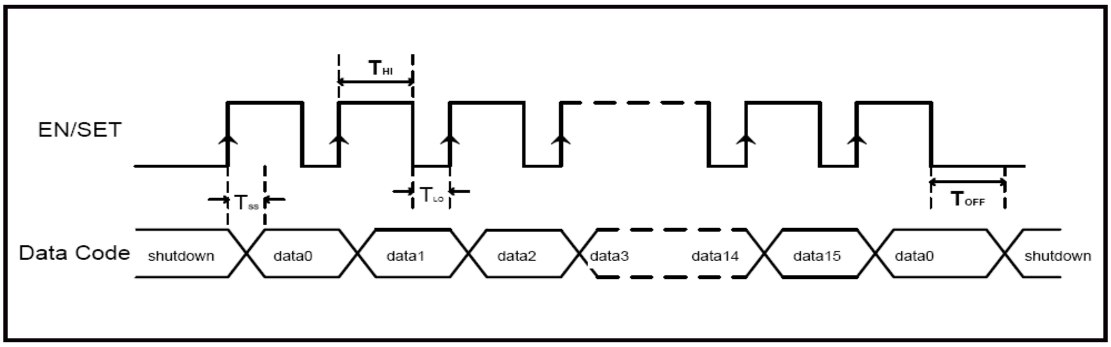
SINGLE-WIRE PULSE-PROGRAMMING INTERFACE

The current sink input magnitude on the ft3356 is controlled by Fangtek's single-wire pulse programming interface. The interface records rising edges of the EN/SET pin and decodes them into 16 different states, as indicated in Table 1. There are four brightness levels for the main or sub-display group with the possibility of individually turning ON or OFF each group. To further optimize power efficiency, the ft3356 also offers four low-current levels for dim LED operation (Data 12 through 15). The Single-Wire Pulse-Programming interface has flexible timing. Data can be clocked-in at speeds greater than 1MHz, or much slower, such as 15kHz. After data is submitted, EN/SET is held high to remain the state. For subsequent current level programming, the number of rising edges corresponding to the desired code must be entered on the EN/SET pin. When EN/SET is held low for an amount of time greater than TOFF, the ft3356 enters into shutdown mode and draws less than 1μA from VIN. The internal data register is reset to zero during shutdown.

Data	Main Group (D1-D4) I_{OUT} (mA)	Sub Group(D5-D6) I_{OUT} (mA)
0	20	20
1	14	14
2	10	10
3	7	7
4	20	0
5	14	0
6	10	0
7	7	0
8	0	20
9	0	14
10	0	10
11	0	7
12	0.05	0.05
13	0.5	0.5
14	1	1
15	2	2

Table1: ft3356 Current Settings

SINGLE-WIRE PULSE-PROGRAMMING INTERFACE TIMING



THERMAL PROTECTION

The ft3356 has a built-in thermal protection circuit that will shut down the charge pump if the die temperature rises above the thermal limit, as is the case where a short-circuit condition at V_{OUT} pin is detected.

APPLICATION INFORMATION

LED SELECTION

Although the ft3356 is specifically intended for driving white LEDs, the device can also be used to drive most types of LEDs with forward voltage specifications ranging from 2.0V to 4.7V. LED applications may include main and sub-LCD display backlighting, camera photo-flash applications, color (RGB) LEDs, infrared (IR) diodes for remotes, and other loads benefiting from a controlled output current generated from a varying input voltage. Since the D1 to D6 input current sinks are matched with negligible voltage dependence, the LED brightness will be matched regardless of the specific LED forward voltage (V_F) levels. In some instances (e.g., in high luminous output applications such as photo flash), it may be necessary to drive high-V_F type LEDs. The low-dropout current sinks in the ft3356 make it capable of driving LEDs with forward voltages as high as 4.7V at full current from an input supply as low as 3.0V. Outputs can be paralleled to drive high-current LEDs without complication.

UNUSED LED CHANNELS

For applications not requiring all the channels, it is recommended the unused LED pins be tied directly to V_{OUT}, otherwise the part will operate only in 2X charge pump mode.(See following Figure)

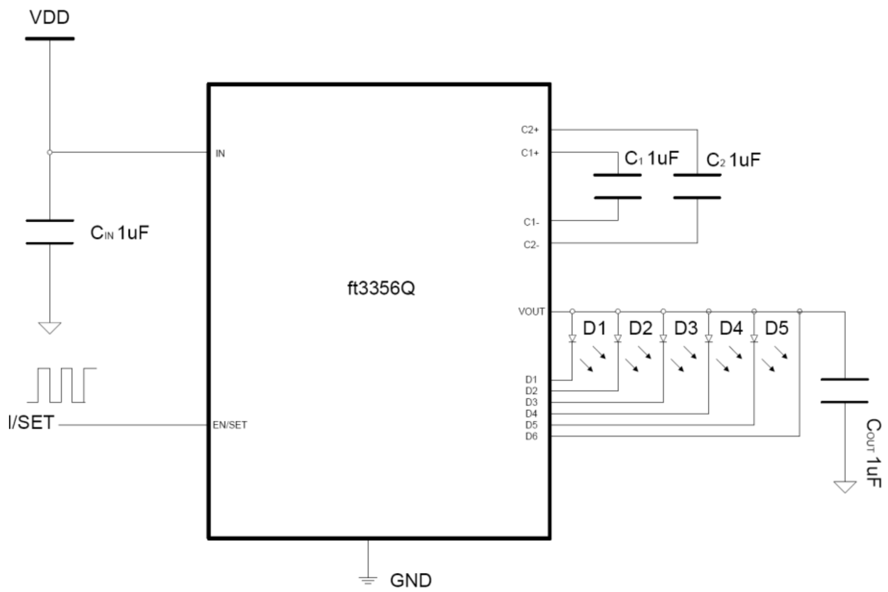


Figure 20: 5 LEDs Typical

DEVICE SWITCHING NOISE PERFORMANCE

The ft3356 operates at a fixed frequency of approximately 1MHz to control noise and limit harmonics that can interfere with the RF operation of cellular telephone handsets or other communication devices. Back-injected noise appearing on the input pin of the charge pump is 20mV peak-to-peak, typically ten times less than inductor-based DC/DC boost converter white LED backlight solutions. The ft3356 soft-start feature prevents noise transient effects associated with inrush currents during start-up of the charge pump circuit.

POWER EFFICIENCY AND DEVICE EVALUATION

The charge pump efficiency discussion in the following sections only accounts for the efficiency of the charge pump section itself. Due to the unique circuit architecture and design of the ft3356, it is very difficult to measure efficiency in terms of a percent value comparing input power over output power. Since the ft3356 inputs are pure constant current sinks and typically drive individual loads, it is difficult to measure the output voltage for a given input (D1 to D6) to derive an overall output power measurement. For any given application, white LED forward voltage levels can differ, yet the load drive current will be maintained as a constant. This makes quantifying output power a difficult task when taken in the context of comparing to other white LED driver circuit topologies. A better way to quantify total device efficiency is to observe the total input power to the device for a given LED current drive level. The best white LED driver for a given application should be based on trade-offs of size, external component count, reliability, operating range, and total energy usage...not just % efficiency.

The ft3356 efficiency may be quantified under very specific conditions and is dependent upon the input voltage versus the output voltage seen across the loads applied to inputs D1 through D6 for a given constant current setting. Depending on the combination of V_{IN} and voltages sensed at the current sinks, the device will operate in load switch mode. When any one of the voltages sensed at the current sinks nears dropout, the device will operate in 1.33x, 1.5X or 2X charge pump mode. Each of these modes will yield different efficiency values. Refer to the following two sections for explanations for each operational mode.

LOAD SWITCH MODE EFFICIENCY

The ft3356 load switch mode control is operational at all times to enhance the power conversion efficiency. When V_{IN} is greater than the voltage across the load, the mode of 1X is selected and the conversion efficiency defined as output power divided by input power:

$$\eta = \frac{P_{OUT}}{P_{IN}}$$

The expression to define the ideal efficiency can be rewritten as:

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times I_{OUT}} = \frac{V_{OUT}}{V_{IN}}$$

or

$$\eta(\%) = 100\left(\frac{V_{OUT}}{V_{IN}}\right)$$

CHARGE PUMP SECTION EFFICIENCY

The ft3356 contains a fractional charge pump that will boost the input supply voltage when V_{IN} is less than the voltage required on the constant current sink inputs. The efficiency can be simply defined as a linear voltage regulator with an effective output voltage that is equal to 1.33X, 1.5X, or 2X of the input voltage. Efficiency for an ideal 1.5X charge pump can typically be expressed as the output power divided by the input power:

$$\eta = \frac{P_{OUT}}{P_{IN}}$$

In addition, with an ideal 1.5X charge pump, the output current may be expressed as 2/3 of the input current.

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times 1.5 I_{OUT}} = \frac{V_{OUT}}{1.5 V_{IN}}$$

The expression to define the ideal efficiency can be rewritten as:

$$\eta(\%) = 100\left(\frac{V_{OUT}}{1.5 V_{IN}}\right)$$

CAPACITOR SELECTION

Careful selection of the four external capacitors C_{IN}, C_1, C_2, and C_{OUT} is important because they will affect turn-on time, output ripple, and transient performance. Optimum performance will be obtained when low equivalent series resistance (ESR) ceramic capacitors are used. In general, low ESR may be defined as less than 100mΩ. A value of 1μF for all four capacitors is a good starting point when choosing capacitors. If the LED current sources are only programmed for light current levels, then the capacitor size may be decreased.

Capacitor Characteristics: Ceramic composition capacitors are highly recommended over all other types of capacitors for use with the ft3356. Ceramic capacitors offer many advantages over their tantalum and aluminum electrolytic counterparts including low ESR, lowest cost, smaller PCB footprint, and non-polarity. Low ESR ceramic capacitors help to maximize charge pump transient response. Since ceramic capacitors are non-polarized, they are not prone to incorrect connection damage.

EQUIVALENT SERIES RESISTANCE

ESR is an important characteristic to be considered when selecting a capacitor. ESR is a resistance internal to a capacitor that is caused by the leads, internal connections, size or area, material composition, and ambient temperature. Capacitor ESR is typically measured in milliohms for ceramic capacitors and can range to more than several ohms for tantalum or aluminum electrolytic capacitors.

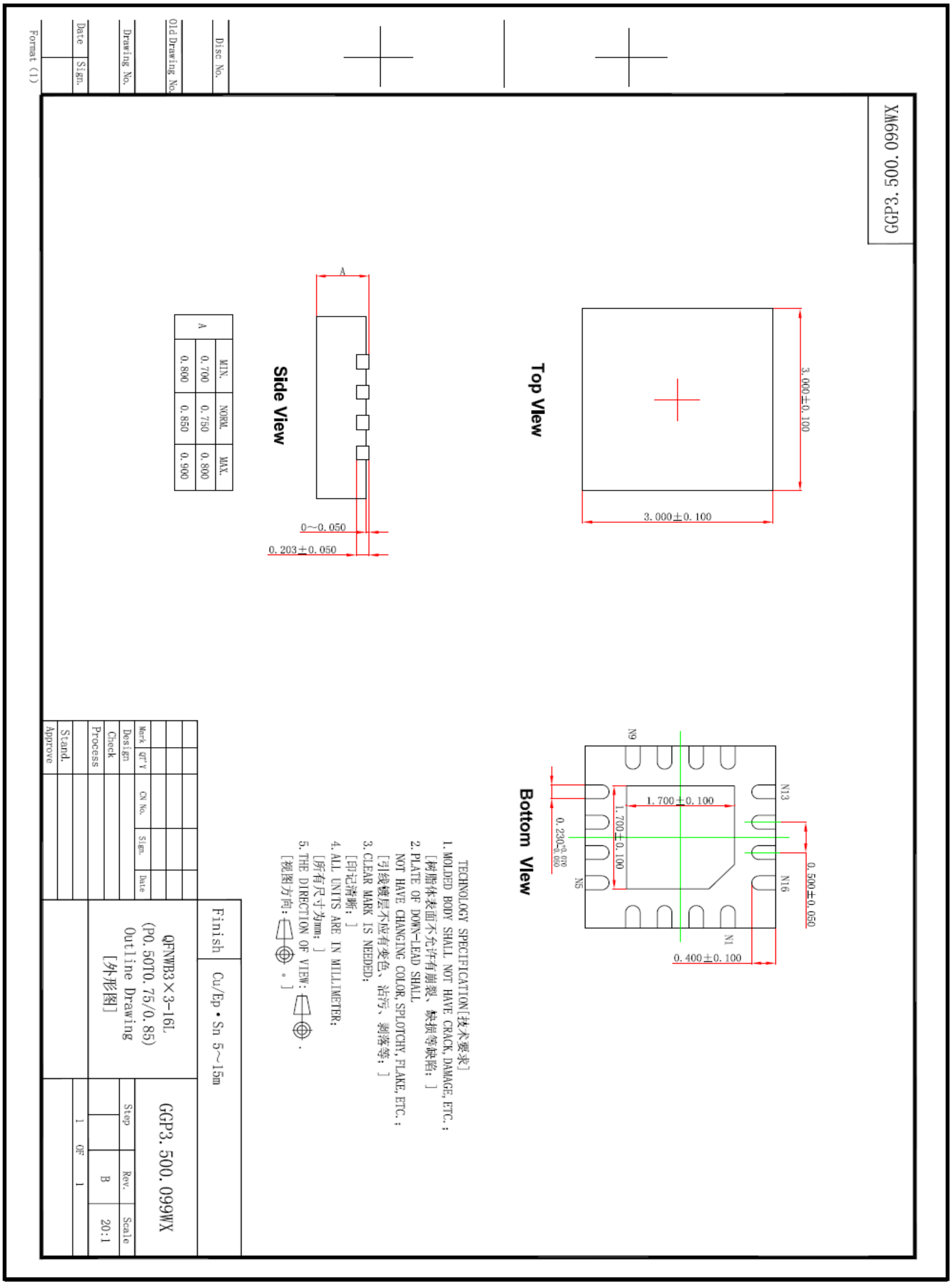
CERAMIC CAPACITOR MATERIALS

Ceramic capacitors less than 0.1μF are typically made from NPO or C0G materials. NPO and C0G materials generally have tight tolerance and are very stable over temperature. Larger capacitor values are usually composed of X7R, X5R, Z5U, or Y5V dielectric materials. Large ceramic capacitors (i.e., greater than 2.2μF) are often available in low-cost Y5V and Z5U dielectrics, but capacitors greater than 1μF are not typically required for ft3356 applications. Capacitor area is another contributor to ESR. Capacitors that are physically large will have a lower ESR when compared to an equivalent material smaller capacitor. These larger devices can improve circuit transient response when compared to an equal value capacitor in a smaller package size.

PHYSICAL DIMENSIONS

ft3356

QFN3mmX3mm-16L



Unit: millimeters.

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