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## Step Up Current Mode PWM Converter with 4+1 Operational Amplifiers

### Features

- Built in 1.6A, 0.23 Switching NMOS
- Fault and Thermal Protection
- Internal Soft-Start Function
- Selectable Frequency : 600 kHz or 1.25MHz
- Low Dissipation Current :  
Typical 1.6mA in Operation
- Four Channels  $V_{\text{GAMMA}}$  with Output Current:  
 $\pm 30\text{mA}$  (MAX)
- One channel  $V_{\text{COM}}$  with Output Current:  
 $\pm 100\text{mA}$  (MAX)
- TSSOP-20 Package Available

### Pin Configuration

(Top View)

SW	1	20	GND1
$V_{\text{DD}}$	2	19	GND
SHDN	3	18	IN1
FREQ	4	17	EO
$V_{\text{DD1}}$	5	16	N.C
CIN+	6	15	COUT
GI1	7	14	GO1
GI2	8	13	GO2
GI3	9	12	GO3
GI4	10	11	GO4

TSSOP-20 PACKAGE

### General Description

The AAT1160 is a step up current mode PWM converter that provides a one-channel step-up PWM controller, four Gamma buffers, and one  $V_{\text{COM}}$  buffer. Internal soft-start function can efficiently prevent inrush current when the power is on.

This PWM controller consists of an on-chip voltage reference, error amplifier, current sense, pulse width modulation controller, under-voltage lockout protection, thermal detect, soft-start, and fault protection circuits.

The AAT1160 contains 4+1 operational amplifiers: GO1, GO2, GO3, and GO4 for gamma corrections and COUT for  $V_{\text{COM}}$ .

$V_{\text{COM}}$  and  $V_{\text{GAMMA}}$  are designed to increase driving capability for thin film transistor liquid crystal display (TFT LCD). Each buffer is capable of driving heavy load and offering fast current loading ( $V_{\text{COM}} : \pm 100\text{mA}$ , and  $V_{\text{GAMMA}} : \pm 30\text{mA}$ ). With minimal external components, the AAT1160 offers a simple and economical power management solution for TFT LCD panels.

– 台灣類比科技股份有限公司 –  
– Advanced Analog Technology, Inc. –

**Pin Description**

<b>PIN NO.</b>	<b>NAME</b>	<b>I/O</b>	<b>DESCRIPTION</b>
1	SW	O	High Voltage Switch Output
2	V <sub>DD</sub>	-	Power Supply
3	SHDN	I	Shutdown Control Pin; High for Enable
4	FREQ	I	Frequency Select Pin
5	V <sub>DD1</sub>	-	High Voltage Power Supply
6	CIN+	I	V <sub>COM</sub> Buffer Input
7	GI1	I	Gamma Buffer 1 Input
8	GI2	I	Gamma Buffer 2 Input
9	GI3	I	Gamma Buffer 3 Input
10	GI4	I	Gamma Buffer 4 Input
11	GO4	O	Gamma Buffer 4 Output
12	GO3	O	Gamma Buffer 3 Output
13	GO2	O	Gamma Buffer 2 Output
14	GO1	O	Gamma Buffer 1 Output
15	COUT	O	V <sub>COM</sub> Buffer Output
16	N.C	-	
17	EO	O	PWM Error Amplifier Output Pin
18	IN1	I	Inverting Input Pin of PWM Error Amplifier
19	GND	-	Ground
20	GND1	-	Ground

**Absolute Maximum Ratings**

PARAMETER	SYMBOL	VALUE	UNIT
$V_{DD}$ to GND	$V_{DD}$	7	V
SW to GND	$V_{SW}$	18	V
$V_{DD1}$ to GND	$V_{DD1}$	14	V
Input Voltage 1 (IN1, SHDN, FREQ)	$V_{I1}$	$V_{DD} + 0.3$	V
Input Voltage 2 (CIN+, CI1, CI2, GI3, GI4)	$V_{I2}$	$V_{DD1} + 0.3$	V
Output Voltage 1 (EO)	$V_{O1}$	$V_{DD} + 0.3$	V
Output Voltage 2 (COUT, GO1, GO2, GO3, GO4, SW)	$V_{O2}$	$V_{DD1} + 0.3$	V
Operating Free-Air Temperature Range	$T_C$	-20 to +85	°C
Storage Temperature Range	$T_{DD1}$	-45 to +125	°C
Power Dissipation	$P_d$	700	mW


**Electrical Characteristics,  $V_{DD}= 3V$ ,  $FREQ=GND$ ,  $V_{DD1}= 10V$** 
**Operating Power**

PARAMETER	SYMBOL	TEST CONDITION	MIN	TYP	MAX	UNIT
Input Supply Voltage Range	$V_{DD}$		2.6		5.5	V
VDD Under Voltage Lockout	$V_{UVLO}$	Falling	2.29	2.43	2.57	V
		Rising		2.58		V
Quiescent Current	$I_{VDD}$	$V_{INI}=1.3V$ , not switching		0.36	0.60	mA
		$V_{INI}=1.1V$ , switching		1.2	5.0	mA
Shutdown Current	$I_{SHDN}$	$V_{SHDN}=GND$		0.1	10.0	$\mu A$
Thermal Shutdown	$T_{SHDN}$			160		$^{\circ}C$

**EA (Error Amplifier)**

PARAMETER	SYMBOL	TEST CONDITION	MIN	TYP	MAX	UNIT
Feedback Voltage	$V_{INI}$	Level to produce $V_{EO}=1.265V$	1.247	1.265	1.283	V
Input Bias Current	$I_{BI}$	$V_{INI}=1.265V$		0	40	nA
Feedback-Voltage Line Regulation	$V_{RI}$	Level to produce $V_{EO}=1.265V$ $2.6V < V_{DD} < 5.5V$		0.05	0.15	%/V
Transconductance	$g_m$	$I=5\mu A$	70	105	240	$\mu A / V$
Voltage Gain	$A_V$			1,500		V/V
Fault Detect Trigger Voltage			0.98	1.02	1.06	V

**Oscillator**

PARAMETER	SYMBOL	TEST CONDITION	MIN	TYP	MAX	UNIT
Oscillation Frequency	$f_{OSC}$	$FREQ=GND$	500	600	700	kHz
		$FREQ=V_{DD}$	900	1250	1500	kHz
Maximum Duty Cycle	$D_{MAX}$	$FREQ=GND$	79	85	92	%
		$FREQ=V_{DD}$		85		%



Electrical Characteristics,  $V_{DD}=3V$ ,  $FREQ=GND$ ,  $V_{DD1}=10V$

### N-CHANNEL SWITCH

PARAMETER	SYMBOL	TEST CONDITION	MIN	TYP	MAX	UNIT
Current Limit	$I_{LIM}$	$V_{IN1}=1.1V$ ,	1.1	1.6	2.1	A
On-Resistance	$R_{ON}$	$I_{SW}=1.2A$		0.28	0.50	
Leakage Current	$I_{SWOFF}$	$V_{SW}=12V$		0.01	20.00	$\mu A$

### Soft Start & Fault Detect Time

PARAMETER	SYMBOL	TEST CONDITION	MIN	TYP	MAX	UNIT
Soft Start Time	$t_{SS}$			14		ms
During Fault Protect Trigger Time	$t_{FS}$			55		ms

### Control Inputs Characteristics

PARAMETER	SYMBOL	TEST CONDITION	MIN	TYP	MAX	UNIT
Input Low Voltage	$V_{IL}$				0.3 $V_{DD}$	V
Input High Voltage	$V_{IH}$		0.7 $V_{DD}$			V
Hysteresis	$V_{HYS}$			0.1 $V_{DD}$		V
FREQ Pull Down Current	$I_{PL}$		3.5	5.0	6.5	$\mu A$
SHDN Pull Up Current	$I_{PH}$			0.001	1.000	$\mu A$



Electrical Characteristics,  $V_{DD} = 3V$ ,  $FREQ = GND$ ,  $V_{DD1} = 10V$

### $V_{COM}$ and Gamma Buffer Performance

PARAMETER	SYMBOL	TEST CONDITION	MIN	TYP	MAX	UNIT
Power Supply Rejection Ratio	PSRR	$V_{DD1}$ from 6.5V to 13.5V	-	80	-	dB
Supply Current	$I_{VDD}$		-	1.5	-	mA

### $V_{COM}$ and Gamma Buffer Input Characteristics

PARAMETER	SYMBOL	TEST CONDITION	MIN	TYP	MAX	UNIT
Input Offset Voltage	$V_{OS}$	$V_{CIN+}$ or $V_{GI1-4} = 5V$	-	2	12	mV
Input Bias Current	$I_{B2}$	$V_{CIN+}$ or $V_{GI1-4} = 5V$	-	2	50	nA

### $V_{COM}$ and Gamma Buffer AC Characteristics

PARAMETER	SYMBOL	TEST CONDITION	MIN	TYP	MAX	UNIT
Slew Rate [Note 1]	SR	$V_{CIN+}$ or $V_{GI1-4} = 2V$ to 8V, 20% to 80%	-	12	-	V/ $\mu$ s
Settling Time	$t_s$	$V_{CIN+}$ or $V_{GI1-4} = 4.5V$ to 5.5V 0.1% $V_{CIN+}$ or $V_{GI1-4} = 5.5V$ to 4.5V 0.1%	-	5	-	$\mu$ s

Note 1: Slew rate is measured on rising and falling edges.



Electrical Characteristics,  $V_{DD}=3V$ ,  $FREQ=GND$ ,  $V_{DD1}=10V$

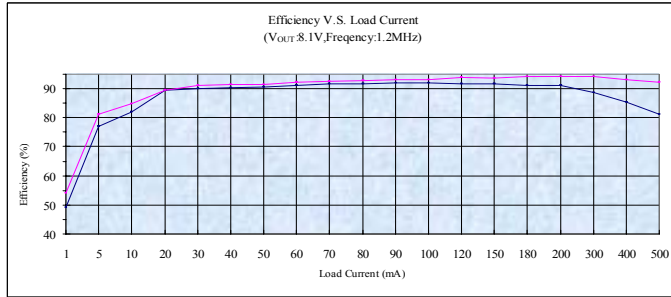
$V_{COM}$  and Gamma Buffer Output Characteristics

PARAMETER	SYMBOL	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Output Swing Low	$V_{OL2}$	$I_{COUT} = 5mA$ ( $V_{COM}$ Buffer) $V_{CIN+} = 0V$	-	0.08	0.15	V
		$I_{GO1-4} = 10mA$ (Gamma Buffer) $V_{GII-4} = 1V$	-	1.02	1.05	
Output Swing High	$V_{OH2}$	$I_{COUT} = -5mA$ ( $V_{COM}$ Buffer) $V_{CIN+} = 10V$	9.85	9.92	-	V
		$I_{GO1-4} = -10mA$ (Gamma Buffer) $V_{GII-4} = 9V$	8.95	8.98	-	
Output Swing (Gamma Buffer)	$V_{OL3}$	$I_{GO1-4} = 10mA$ , $V_{GII-4} = 5V$	-	5.02	5.04	V
	$V_{OH3}$	$I_{GO1-4} = -10mA$ , $V_{GII-4} = 5V$	4.96	4.98	-	
Output Swing ( $V_{COM}$ )	$V_{OL3}$	$I_{COUT} = 50mA$ , $V_{CIN+} = 5V$	-	5.03	5.05	V
	$V_{OH3}$	$I_{COUT} = -50mA$ , $V_{CIN+} = 5V$	4.95	4.97	-	
Short Circuit Current	$I_{SHORT}$	(Gamma Buffer)	-	$\pm 70$	-	mA
		( $V_{COM}$ Buffer)	-	$\pm 180$	-	mA



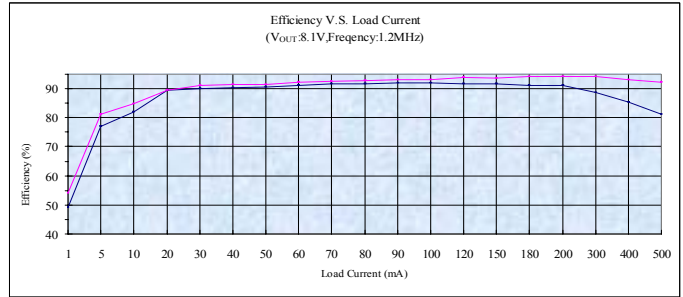
Efficiency vs. Load Current  
( $f_{OSC} = 1.2\text{MHz}$   $V_{OUT} = 8.1\text{V}$ )

L:10 $\mu\text{H}$



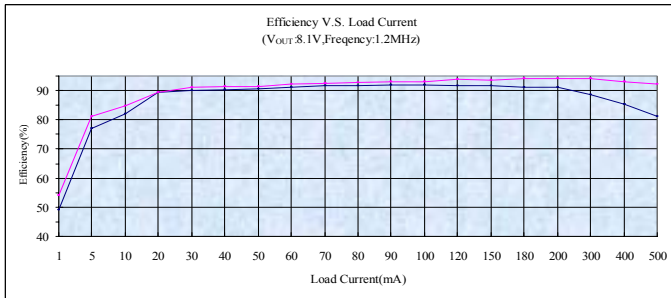
Efficiency vs. Load Current  
( $f_{OSC} = 600\text{kHz}$   $V_{OUT} = 8.1\text{V}$ )

L:10 $\mu\text{H}$



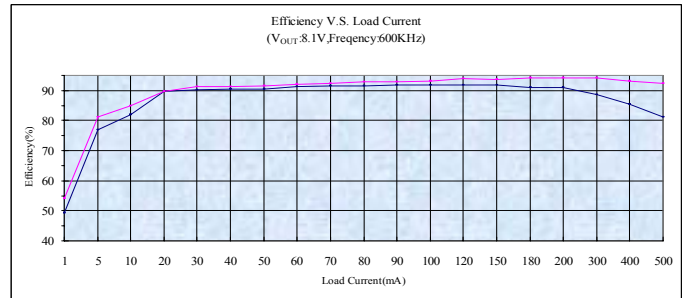
Efficiency vs. Load Current  
( $f_{OSC} = 1.2\text{MHz}$   $V_{OUT} = 8.1\text{V}$ )

L:4.7 $\mu\text{H}$

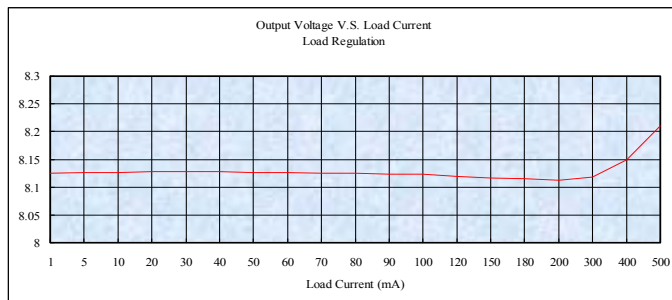


Efficiency vs. Load Current  
( $f_{OSC} = 600\text{kHz}$   $V_{OUT} = 8.1\text{V}$ )

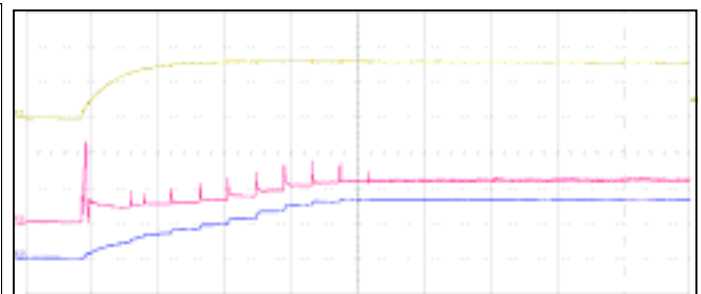
L:4.7 $\mu\text{H}$



### Load Regulation



### Internal Soft Start



CH1:  $V_{IN}$ , 2V/div, DC  $T = 2\text{ms/div}$

CH2:  $I_L$ , 500mA/div, DC

CH3:  $V$ , 5V/div, DC





Load Transient Response



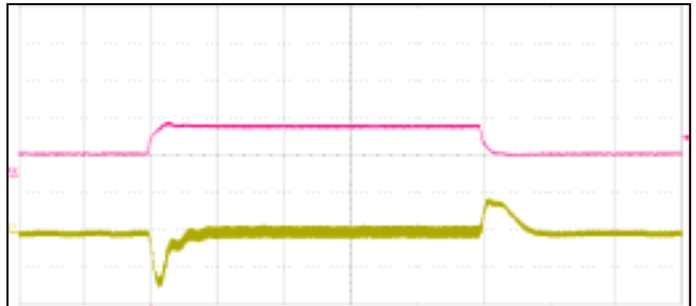
T = 100µs/div

$V_O = 8.1V$ ,  $V_{IN} = 3.3V$ ,  $f_{OSC} = 1.2MHz$

CH1: Load, 100mA to 250mA

CH2:  $V_O$ , 20

Load Transient Response



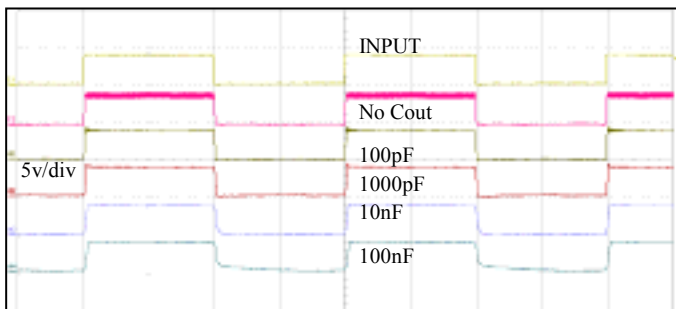
T = 100µs/div

$V_O = 8.1V$ ,  $V_{IN} = 3.3V$ ,  $f_{OSC} = 600kHz$

CH1: Load, 100mA to 250mA

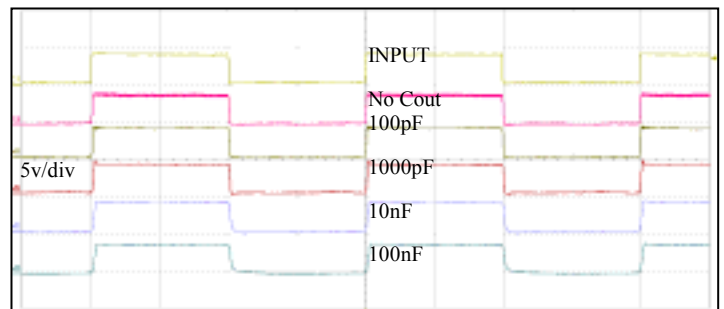
CH2:  $V_O$ , 200mV/div, AC

$V_{GAMMA}$  Signal Response



10 µ s/div

$V_{COM}$  Signal Response



10 µ s/div



## Operation Information:

### Setting the Output Voltage:

Output voltage is set by using a feedback pin and a resistor divider; equation is as follows:

$$V_{PI} = 1.265 (1 + R1/R2)$$

### Soft-Start:

The soft-start function is embedded with a typical setting of 14ms

### Operation Frequency Setting:

Pin4 (FREQ) can set PWM operation to low with  $f_{OSC} = 600\text{kHz}$ , or set PWM operation to high with  $f_{OSC} = 1.2\text{ MHz}$ .

### Diode Selection:

Schottky diode for the boost regulator must be selected correctly depending on the output voltage and the output current. The diode must have a reverse voltage equal to or greater than the output voltage. In addition, the diode current must exceed the switch current limit as a lower forward voltage will increase efficiency.

### Inductor Selection:

$$I_{L(\text{peak})} = I_{IN} + V_{IN} * D / (2 * L * f_s)$$

D: PWM duty

$$V_O / V_{IN} = 1 / (1 - D)$$

Maximum current of the inductor must be greater than  $I_{L(\text{peak})}$

### The Compensation:

Pin17 (EO) series with  $R_C$  &  $C_C$  for compensation, usually range as  $1\text{k} \leq R_C \leq 200\text{k}$ ,  $100\text{pF} \leq C_C \leq 6,800\text{pF}$ . Standard formulas are

only for reference purpose, as PCB has a lot of noise or parasitic capacitance and resistance, it often requires on board adjustment.

The key steps for step-up compensation are as follows:

Transconductance (from FB to CC),  $g_m$  ( $105\mu\text{S}$ )

Current-sense amplifier transresistance,  $R_{CS}$

( $0.275\text{V/A}$ )

For continuous conduction, the right-half-plane zero frequency ( $f_{RHPZ}$ ) is given by the following:

$f_{RHPZ} = V_O (1-D)^2 / (2 * L * I_{LOAD})$  where  $D =$  the duty cycle  $= 1 - (V_{IN} / V_O)$ ,  $L$  is the inductance value, and  $I_{LOAD}$  is the maximum output current. Typical target, crossover ( $f_C$ ), is 1/6 of the RHPZ.

For example, if oscillation frequency is assumed to be  $f_{OSC} = 500\text{kHz}$ ,  $V_{IN} = 2.5\text{V}$ ,  $V_O = 5\text{V}$ , and  $I_{OUT} = 0.5\text{A}$ , then  $R_{LOAD} = 10$ .

If we select  $L = 4.7\mu\text{H}$ , then:

$$f_{RHPZ} = 5(2.5/5)^2 / (2 * 4.7 * 10^{-6} * 0.5) = 84.65\text{kHz}$$

If  $f_C = 14\text{kHz}$ ,  $C_C$  would be calculated as:

$$C_C = (V_{FB} / V_O) (R_{LOAD} / R_{CS}) (g_m / 2\pi * f_C) (1-D) / 2 = (1.25/5)(10/0.275) * [105\mu\text{S} / (6.28 * 14\text{kHz})] (1/4) = 2.7\text{ nF}$$

Now selected  $R_C$  has fulfilled transient-droop requirements. For example, if 4% of transient droop is allowed, input to error amplifier moves



0.04\*1.25V, or 50mV. Error amplifier output drives 50mV\*105μs, or 6.25μA, across R<sub>C</sub> to provide transient gain. Since the current-sense transresistance is 0.275V/A, the value of R<sub>C</sub> that would allow the required load-step swing is as follows:

$$R_C = 0.275 I_{IND(PK)} / 6.25 \mu A$$

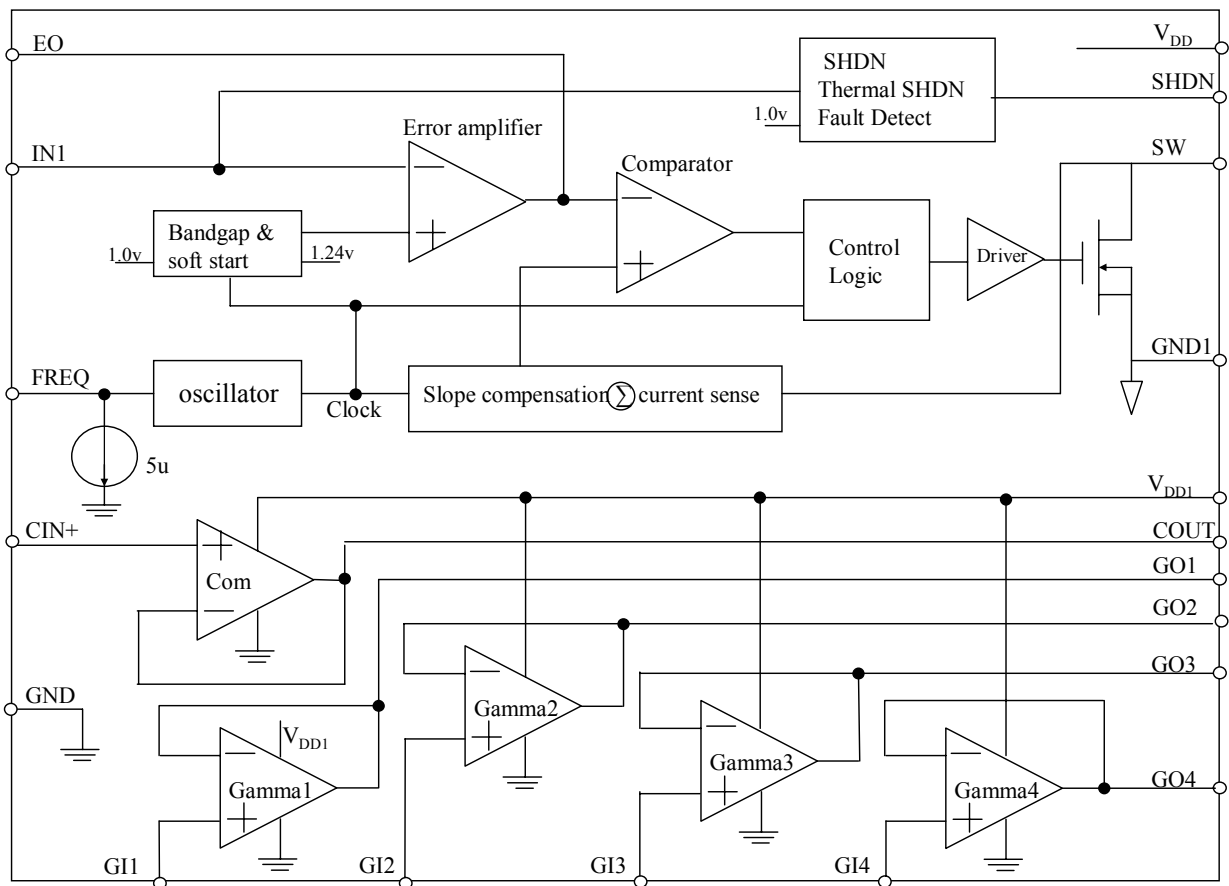
In a step-up DC-to-DC converter, if L<sub>IDEAL</sub> is used, output current would relate to inductor current as:

$$I_{IND(PK)} = 1.25 I_{OUT} / (1-D) = 1.25 I_{OUT} * V_O / V_{IN}$$

Therefore, for a 500mA output load step with V<sub>IN</sub>=2.5V and V<sub>O</sub>=5V:

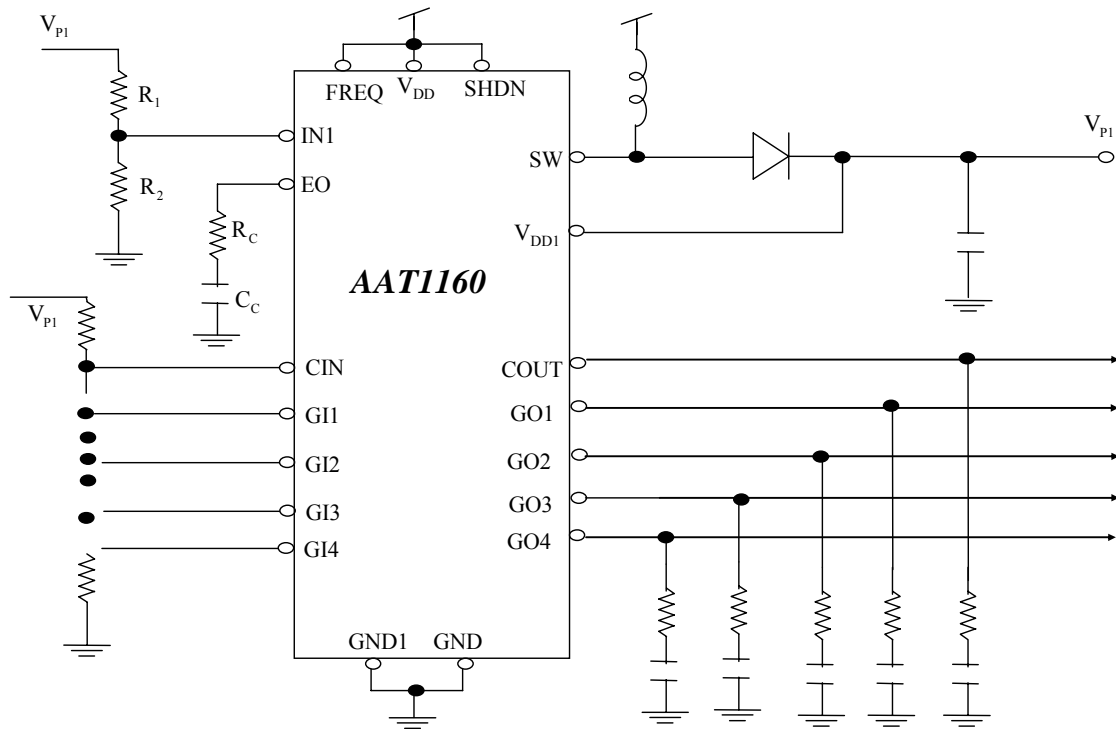
$$R_C = [1.25(0.75 * 0.5 * 5) / 2] / 6.25 \mu A = 18.7 k\Omega$$

**BLOCK DIAGRAM**



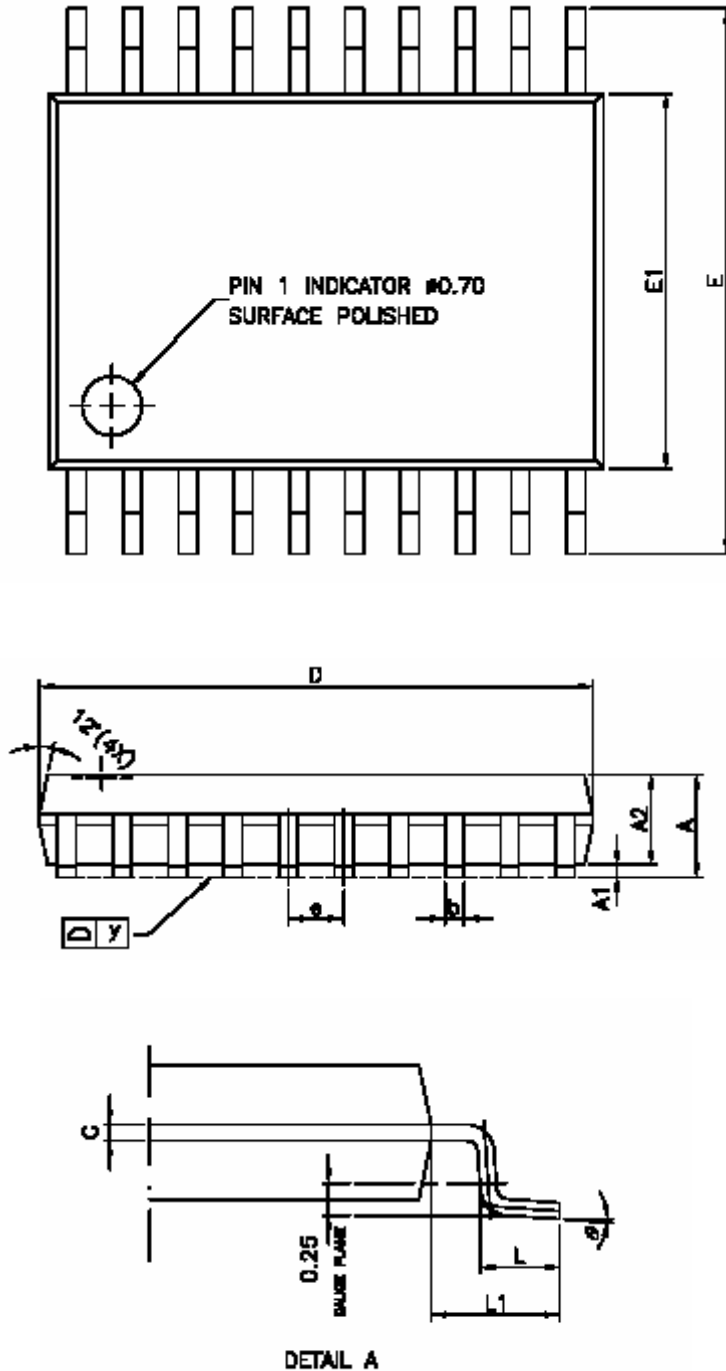


Application Circuit



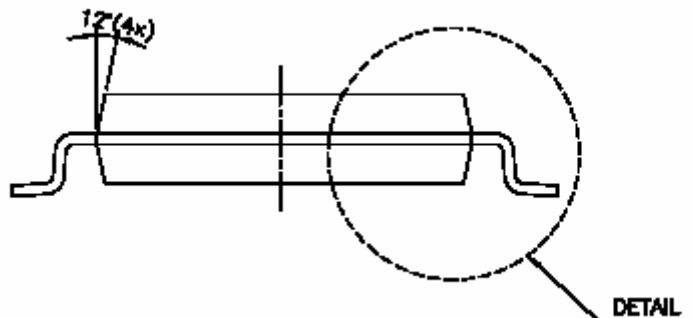


Package Dimension  
20-Pin TSSOP





### Package Dimension (Cont.) 20-Pin TSSOP



SYMBOLS	DIMENSIONS IN MILLIMETERS			DIMENSIONS IN INCHES		
	MIN	NOM	MAX	MIN	NOM	MAX
A	—	—	1.20	—	—	0.047
A1	0.05	—	0.15	0.002	—	0.006
A2	0.08	1.00	1.05	0.003	0.039	0.041
b	0.19	—	0.30	0.007	—	0.012
C	0.09	—	0.20	0.0035	—	0.008
D	6.40	6.50	6.60	0.252	0.256	0.260
E	—	6.40	—	—	0.252	—
E1	4.30	4.40	4.50	0.170	0.173	0.177
e	—	0.65	—	—	0.026	—
L	0.45	0.60	0.75	0.0177	0.024	0.0295
L1	—	1.00	—	—	0.039	—
y	0°	—	8°	0°	—	8°
Ø	—	—	0.076	—	—	0.003

## NOTE :

1. CONTROLLING DIMENSION : mm
2. LEAD FRAME MATERIAL : OLIN C7025/EFTEC 64T
3. DIMENSION "D" DOES NOT INCLUDE MOLD FLASH, TIE BAR BURRS AND GATE BURRS. MOLD FLASH, TIE BAR BURRS AND GATE BURRS SHALL NOT EXCEED 0.006[0.15mm] PER END DIMENSION "E1" DOES NOT INCLUDE INTERLEAD FLASH. INTERLEAD FLASH SHALL NOT EXCEED 0.010[0.25mm] PER SIDE.
4. DIMENSION "b" DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE 0.003[0.08mm] TOTAL IN EXCESS OF THE "b" DIMENSION AT MAXIMUM MATERIAL CONDITION. DAMBAR CANNOT BE LOCATED ON THE LOWER RADIUS OR THE FOOT. MINIMUM SPACE BETWEEN PROTRUSION AND AN ADJACENT LEAD TO BE 0.0028[0.07mm]
5. TOLERANCE : ±0.010[0.25mm] UNLESS OTHERWISE SPECIFIED.
6. OTHERWISE DIMENSION FOLLOW ACCEPTABLE SPEC.
7. REFERENCE DOCUMENT : JEDEC SPEC MO-153