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# LP3905 Power Management Unit For Low Power Handheld Applications

## General Description

LP3905 is a multi-functional Power Management Unit, optimized for low power handheld applications. This device integrates two 600mA DC/DC buck regulators and two 150mA linear regulators. Fixed and adjustable buck output versions are available. The LP3905 additionally features two enable pins for the device output control and is offered in an LLP package.

## Features

- Two buck regulators for powering high current processor functions or peripheral devices
- Two linear regulators for powering internal processor functions and I/Os
- One enable pin for Buck1 and Linear Regulators 1 & 2
- Separate enable pin for Buck2
- Thermal and current overload protection
- Small 14-Pin LLP package (4mm x 4mm x 0.8mm)

## Applications

- Baseband Processors
- Peripheral Processor (Video, Audio)
- I/O Power
- FPGA Power

## Key Specifications

### Buck Regulators

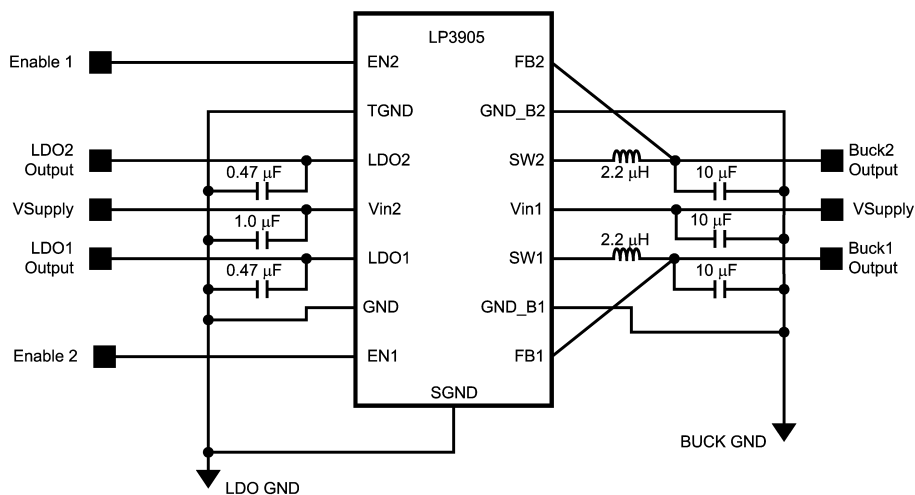
- Fixed and adjustable voltage options, range 1.0V to 3.3V \*
- Up to 90% Efficiency
- Auto-switching PFM-PWM mode and fixed PWM mode
- 2MHz PWM fixed switching frequency (Typ)
- 600mA output current
- $\pm 4\%$  output voltage accuracy over temp.
- Internal softstart
- 2.2 $\mu$ H inductor, 10 $\mu$ F Input and 10 $\mu$ F output Caps

### Linear Regulators

- Output options in the range 1.5V to 3.3V \*
- 13.5 $\mu$ V<sub>rms</sub> output voltage noise
- PSRR - 70dB @ 1kHz
- $\pm 3\%$  output voltage accuracy over full line and load regulation
- 0mA to 150mA output current
- C<sub>in</sub> = 1.0 $\mu$ F, C<sub>out</sub> = 0.47 $\mu$ F for 100mA O/P  
C<sub>in</sub> = 1.0 $\mu$ F, C<sub>out</sub> = 1.0 $\mu$ F for 150mA O/P  
80mV Dropout voltage

\* Fixed output voltage devices can be customized to fit system requirements. Please contact National Semiconductor Sales Office.

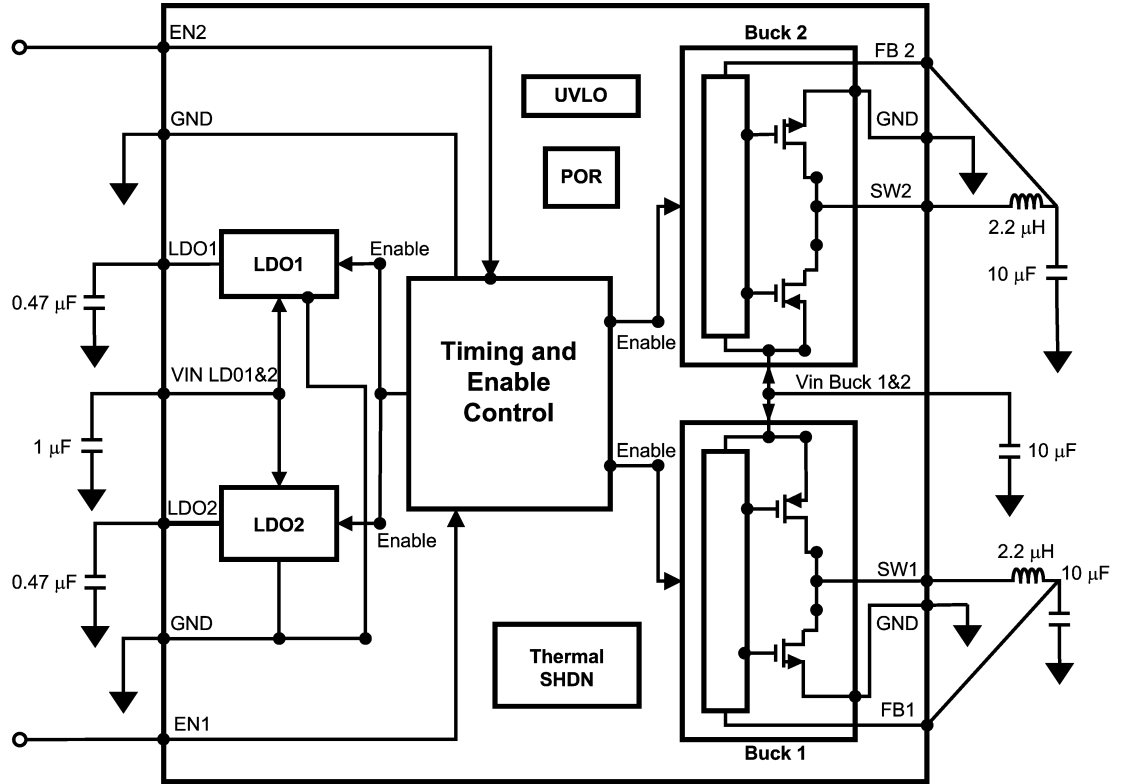
## Typical Application Circuit



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FIGURE 1. Typical Application Circuit – 14 Pin LLP Package

### Block Diagram

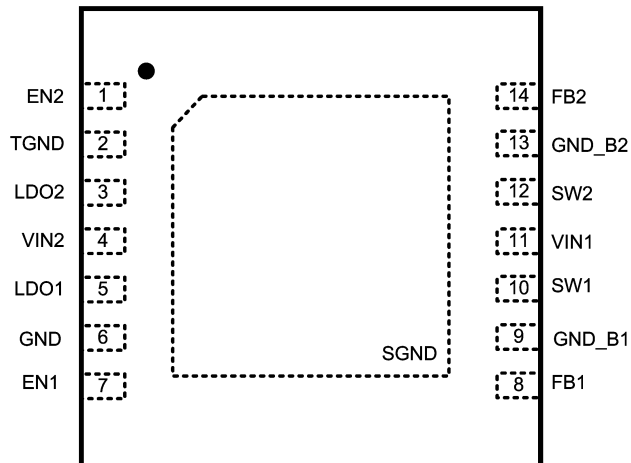


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FIGURE 2. Simplified Functional Diagram

### Connection Diagram

LP3905 LLP-14 Package  
TOP VIEW



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FIGURE 3. 14 Pin LLP Package

## Connection Diagram (Continued)

### Pin Descriptions

Pin #	Name	Description
1	EN2	Enable Pin for Buck2
2	TGND	Ground Pin
3	LDO2	LDO2 Output Pin
4	VIN2	Input Power Terminal to LDO1 & 2
5	LDO1	LDO1 Output Pin
6	GND	LDO1 & 2 Ground Pin
7	EN1	Enable Pin for Buck1 and LDO1&2
8	FB1	Buck1 Feedback Pin
9	GND_B1	Buck1 Ground Pin
10	SW1	Buck1 Switch Pin
11	VIN1	Input Power Terminal to Buck1 & 2
12	SW2	Buck2 Switch Pin
13	GND_B2	Buck2 Ground Pin
14	FB2	Buck2 Feedback Pin
DAP	SGND	Die Attach Pad (DAP)

### Package Marking Diagram



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- The physical placement of the package marking will vary from part to part.
- Date Code - UZXYTT format. 'U' - Wafer fab code; 'Z' - assembly site code; 'XY' 2 digit date code; 'TT' die run code
- See National Web site for more info - [http://www.national.com/quality/marketing\\_conventions.html](http://www.national.com/quality/marketing_conventions.html)

**FIGURE 4. LP3905 14 Pin LLP Package Marking**  
NS package number SDA14B

### Ordering Information

Buck 1 [V]	Buck 2 [V]	LDO 1 [V]	LDO 2 [V]	Order Number	Package Marking	Supplied As
1.2	1.875	2.8	2.8	LP3905SD-00	3905-00	1000 units, Tape-and-Reel
				LP3905SDX-00		4500 units, Tape-and-Reel
1.2 Fixed PWM	1.875 Fixed PWM	2.8	2.8	LP3905SD-30	3905-30	1000 units, Tape-and-Reel
				LP3905SDX-30		4500 units, Tape-and-Reel
ADJ	ADJ	3.0	2.8	LP3905SD-A3	3905-A3	1000 units, Tape-and-Reel
				LP3905SDX-A3		4500 units, Tape-and-Reel

**Absolute Maximum Ratings** (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

$V_{IN1}, V_{IN2}$	-0.2V to 6.0V
FB1, FB2, EN1, EN2	(GND-0.2V) to ( $V_{IN} + 0.2V$ ) to 6.0V (max)
Continuous Power Dissipation (Note 3)	Internally Limited
Junction Temperature ( $T_{J-MAX}$ )	+150°C
Storage Temperature Range	-65°C to +150°C
Maximum Lead Temperature (Soldering, 10 sec.)	260°C
ESD Rating (Note 4)	
Human Body Model:	2.5kV

**Operating Ratings** (Notes 1, 2)

$V_{IN1}$ (Buck1&2 Input Voltage), $V_{IN2}$ (LDO1&2 Input Voltage) (Note 7)	3V to 5.5V
Recommended Load Current (Buck)	0mA to 600 mA
Recommended Load Current (LDO)	0mA to 100mA with 0.47uF O/P cap 0mA to 150mA with 1.0uF O/P cap
Junction Temperature ( $T_J$ ) Range	-40°C to +125°C
Ambient Temperature ( $T_A$ ) Range (Note 5)	-40°C to +85°C

**Thermal Properties**

Junction-to-Ambient	37.3°C/W
Thermal Resistance ( $\theta_{JA}$ ) SDA14B package (Note 6)	

**General Electrical Characteristics** (Notes 2, 8, 9)

Limits in standard typeface are for  $T_J = 25^\circ\text{C}$ . Limits in **boldface** type apply over the full junction temperature range ( $-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ ). Unless otherwise noted, specifications apply to the LP3905 Typical Application Circuit (Figure. 1)

Symbol	Parameter	Condition	Min	Typ	Max	Units
<b>Login Input Thresholds</b>						
$V_{IN}$	Input Voltage Range		3		5.5	V
$I_Q$	Shutdown Supply Current	All Circuits OFF except for POR and UVLO		6.5	10.0	$\mu\text{A}$
	No load Supply Current (Note 15)	LDO1 & 2 and Buck1 & 2 on <b>( PWM only versions )</b> LDO1 & 2 and Buck1 & 2 on		140 7	250 10.0	$\mu\text{A}$ mA
$V_{IH}$	Logic High Input	$V_{IN} = 3.0V$ to 5.5V	<b>1.2</b>			V
$V_{IL}$	Logic Low Input	$V_{IN} = 3.0V$ to 5.5V			<b>0.4</b>	V
$I_{EN}$	Enable (EN1,2) Input Current (Note 14)	EN1/EN2 = 5.5V and $V_{IN} = 5.5V$	<b>2.1</b>	5	<b>8.5</b>	$\mu\text{A}$
		EN1/EN2 = 0V and $V_{IN} = 5.5V$		0.001	0.1	$\mu\text{A}$
$V_{UVLO-R}$	Battery Under Voltage Lock-Out	$V_{IN}$ Rising		2.7	3.1	V
$T_{SHUTDOWN}$	Thermal Shutdown (Note 15)	Temperature		160		°C
		Hysteresis		20		

## General Electrical Characteristics (Notes 2, 8, 9) (Continued)

### Buck Regulator Electrical Characteristics

Buck 1 & 2 have a current rating of  $I_{max} = 600\text{mA}$ . Unless otherwise specified, limits are set with  $V_{IN} = V_{EN1/2} = 3.8\text{V}$ ,  $V_{OUT(Buck1)} = V_{nom1}$ ,  $V_{OUT(Buck2)} = V_{nom2}$  and  $C_{IN} = C_{OUT} = 10\mu\text{F}$ . Limits in standard typeface are for  $T_J = 25^\circ\text{C}$ . Limits in **boldface** type apply over the full junction temperature range ( $-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ ). Unless otherwise noted, specifications apply to the LP3905 Typical Application Circuit (Figure. 1) (Notes 2, 8)

Symbol	Parameter	Condition	Min	Typ	Max	Units
$V_{FB}$	Feedback Voltage	(Note 16)	<b>-4</b>		<b>+4</b>	%
$V_{OUT}$	Line Regulation	$3.0\text{V} \leq V_{IN} \leq 5.5\text{V}$ $I_O = 1\text{mA}$		0.045		%/V
	Load Regulation	$100\text{mA} \leq I_O \leq 600\text{mA}$		0.002		%/mA
$R_{DS(on)(P)}$	Pin-Pin Resistance for PFET	$V_{IN} = V_{GS} = 3.6\text{V}$		380	500	m $\Omega$
$R_{DS(on)(N)}$	Pin-Pin Resistance for NFET	$V_{IN} = V_{GS} = 3.6\text{V}$ (Note 15)		250	400	m $\Omega$
$I_{LIM}$	Switch Peak Current Limit	Open Loop	<b>650</b>	1000	<b>1220</b>	mA
$F_{OSC}$	Internal Oscillator Frequency	PWM Mode		2		MHz
$\eta$	Efficiency	$I_{OUT} = 5\text{mA}$ , PFM mode (Note 15)	88			%
		$I_{OUT} = 300\text{mA}$ , PWM mode (Note 15)	90			

### LDO Regulator Electrical Characteristics

The linear regulators have a current rating of  $I_{max} = 150\text{mA}$  with  $C_{OUT} = 1.0\mu\text{F}$ . A 100mA rating applies with  $C_{OUT} = 0.47\mu\text{F}$ . Unless otherwise specified, limits are set with  $V_{IN} = 3.8\text{V}$ ,  $V_{EN1/2} = 3.8\text{V}$ ,  $C_{IN} = 1\mu\text{F}$ ,  $C_{OUT} = 0.47\mu\text{F}$ ,  $I_{OUT} = 1.0\text{mA}$ . Limits in standard typeface are for  $T_J = 25^\circ\text{C}$ . Limits in **boldface** type apply over the full junction temperature range ( $-40^\circ\text{C} \leq T_J \leq +125^\circ\text{C}$ ). Unless otherwise noted, specifications apply to the LP3905 Typical Application Circuit (Figure. 1)(Notes 2, 8)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
$\Delta V_{OUT}$	Output Voltage Tolerance	Over Full Line and Load Regulation	<b>-3</b>		<b>3</b>	%
	Line Regulation Error	$V_{IN} = 3.8\text{V}$ to $5.5\text{V}$ , $I_{OUT} = 1\text{mA}$		0.05		%/V
	Load Regulation Error	$I_{OUT} = 1\text{mA}$ to $100\text{mA}$		0.003		%/mA
$I_{LOAD}$	Load Current	(Notes 11, 15)	0			mA
$V_{DO}$	Dropout Voltage	$I_{OUT} = 100\text{mA}$		80	<b>150</b>	mV
$I_{SC}$	Short Circuit Current Limit	(Note 13)		300	<b>500</b>	mA
$I_{OUT}$	Maximum Output Current	$C_{OUT} = 1.0\mu\text{F}$	<b>150</b>			mA
PSRR	Power Supply Rejection Ratio (Note 15)	$f = 100\text{Hz}$ , $I_{OUT} = 100\text{mA}$		90		dB
		$f = 1\text{kHz}$ , $I_{OUT} = 100\text{mA}$		90		
		$f = 10\text{kHz}$ , $I_{OUT} = 100\text{mA}$		60		
		$f = 50\text{kHz}$ , $I_{OUT} = 100\text{mA}$		35		
		$f = 100\text{kHz}$ , $I_{OUT} = 100\text{mA}$		25		
$e_n$	Output Noise Voltage (Note 15)	BW = 10Hz to 100kHz, $V_{IN} = 4.2\text{V}$ Buck1 Turned ON with $I_{LOAD} = 0\text{mA}$ , Buck2 Turned OFF	$I_{OUT} = 1\text{mA}$		13.5	$\mu\text{V}_{RMS}$
			$I_{OUT} = 100\text{mA}$		15.5	

## General Electrical Characteristics (Notes 2, 8, 9) (Continued)

### LDO Regulator Electrical Characteristics (Continued)

The linear regulators have a current rating of  $I_{\max} = 150\text{mA}$  with  $C_{\text{OUT}} = 1.0\mu\text{F}$ . A 100mA rating applies with  $C_{\text{OUT}} = 0.47\mu\text{F}$ . Unless otherwise specified, limits are set with  $V_{\text{IN}} = 3.8\text{V}$ ,  $V_{\text{EN1/2}} = 3.8\text{V}$ ,  $C_{\text{IN}} = 1\mu\text{F}$ ,  $C_{\text{OUT}} = 0.47\mu\text{F}$ ,  $I_{\text{OUT}} = 1.0\text{mA}$ . Limits in standard typeface are for  $T_{\text{J}} = 25^{\circ}\text{C}$ . Limits in **boldface** type apply over the full junction temperature range ( $-40^{\circ}\text{C} \leq T_{\text{J}} \leq +125^{\circ}\text{C}$ ). Unless otherwise noted, specifications apply to the LP3905 Typical Application Circuit (Figure. 1)(Notes 2, 8)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
<b>Transient Characteristics (Note 15)</b>						
$\Delta V_{\text{OUT}}$	Line Transient (Note 15)	$V_{\text{IN}} = (V_{\text{OUT(NOM)}} + 1.0\text{V})$ to $(V_{\text{OUT(NOM)}} + 1.6\text{V})$ in $10\mu\text{s}$ , $I_{\text{OUT}} = 1\text{mA}$	<b>6</b>			mV
		$V_{\text{IN}} = (V_{\text{OUT(NOM)}} + 1.6\text{V})$ to $(V_{\text{OUT(NOM)}} + 1.0\text{V})$ in $10\mu\text{s}$ , $I_{\text{OUT}} = 1\text{mA}$			<b>6</b>	
	Load Transient (Note 15)	$I_{\text{OUT}} = 1\text{mA}$ to $100\text{mA}$ in $10\mu\text{s}$	<b>-70</b>			mV
		$I_{\text{OUT}} = 100\text{mA}$ to $1\text{mA}$ in $10\mu\text{s}$			<b>30</b>	
		$I_{\text{OUT}} = 1\text{mA}$ to $150\text{mA}$ in $10\mu\text{s}$ $C_{\text{OUT}} = 1.0\mu\text{F}$	<b>-100</b>			
		$I_{\text{OUT}} = 150\text{mA}$ to $1\text{mA}$ in $10\mu\text{s}$ $C_{\text{OUT}} = 1.0\mu\text{F}$			<b>35</b>	
	Overshoot on Startup	(Note 15)			<b>20</b>	mV

## Electrical Characteristics Notes

**Note 1:** Absolute Maximum Ratings indicate limits beyond which damage to the component may occur. Operating Ratings are conditions under which operation of the device is guaranteed. Operating Ratings do not imply guaranteed performance limits. For guaranteed performance limits and associated test conditions, see the Electrical Characteristics tables.

**Note 2:** All voltages are with respect to the potential at the GND pin.

**Note 3:** Internal thermal shutdown circuitry protects the device from permanent damage.

**Note 4:** The Human body model is a 100 pF capacitor discharged through a 1.5 k $\Omega$  resistor into each pin. MIL-STD-883 3015.7

**Note 5:** In Applications where high power dissipation and/or poor package resistance is present, the maximum ambient temperature may have to be derated. Maximum ambient temperature ( $T_{\text{A-MAX}}$ ) is dependent on the maximum operating junction temperature ( $T_{\text{J-MAX}}$ ), the maximum power dissipation of the device in the application ( $P_{\text{D-MAX}}$ ) and the junction to ambient thermal resistance of the package ( $\theta_{\text{JA}}$ ) in the application, as given by the following equation:  $T_{\text{A-MAX}} = T_{\text{J-MAX}} - (\theta_{\text{JA}} \times P_{\text{D-MAX}})$ .

**Note 6:** Junction to ambient thermal resistance is highly dependent on board layout, PCB material environmental conditions and applications. In applications where high power dissipation exists, special care must be given to thermal dissipation issues in board design. The use of thermal vias under the pad may be required. For more on these topics, please refer to the Application Note: AN-1187: Leadless leadframe Package (LLP).

**Note 7:**  $V_{\text{IN1}}$  and  $V_{\text{IN2}}$  should be tied together at all times for proper Power Up

**Note 8:** Min and Max limits are guaranteed by design, test or statistical analysis. Typical numbers are not guaranteed, but do represent the most likely norm.

**Note 9:** The parameters in the electrical characteristic table are tested at  $V_{\text{IN}} = 3.8\text{V}$  unless otherwise specified. For performance over the input voltage range refer to datasheet curves.

**Note 10:**  $C_{\text{IN}}$ ,  $C_{\text{OUT}}$ : Low-ESR Surface-Mount Ceramic Capacitors (MLCCs) used in setting electrical characteristics.

**Note 11:** The device maintains a stable, regulated output voltage without a load.

**Note 12:** Dropout voltage is the voltage difference between the input and the output at which the output voltage drops to 100 mV below its nominal value.

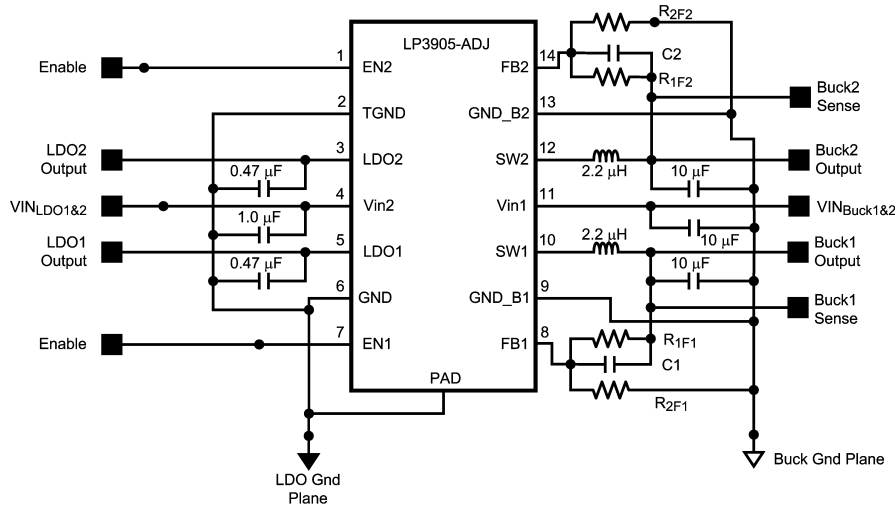
**Note 13:** Short Circuit Current is measured with  $V_{\text{OUT}}$  pulled to 0v and  $V_{\text{IN}}$  worst case = 5.5V.

**Note 14:** There is a 1 M $\Omega$  resistor between EN1, EN2 and ground on the device.

**Note 15:** This specification is guaranteed by design.

**Note 16:** For the adjustable version, feedback resistor values should be chosen for the divider network to ensure that at the desired output voltage the feedback pin is at 0.5V. See Buck Converter Applications Information.

# Typical Application Circuit



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FIGURE 5. Typical Application Circuit For Adjustable Device

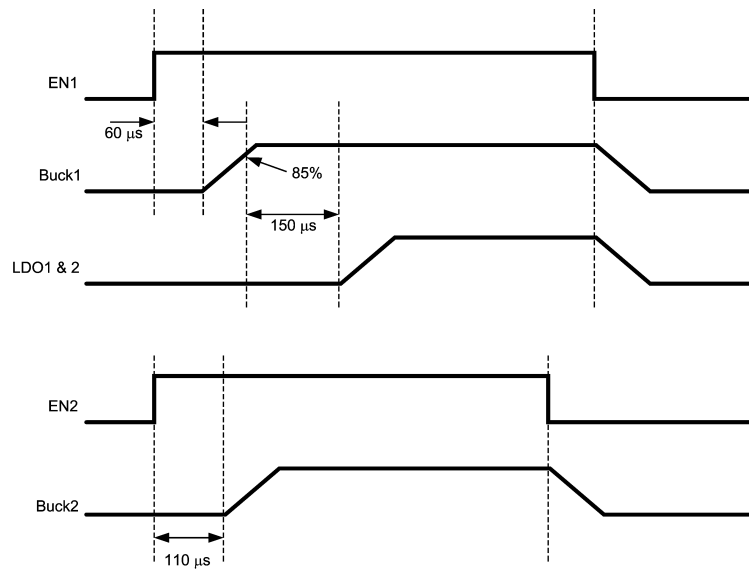
## Functional Description

### POWER UP/DOWN PROCEDURE

The LP3905 Bucks and LDOs are powered UP/DOWN with 2 control pins, EN1 and EN2. In order for the enable pins to operate,  $V_{IN1}$  and  $V_{IN2}$  should be set to a voltage level higher than  $V_{UVLO\_R}$  (specified in electrical characteristic). Once

enabled, EN1 will turn on Buck1, LDO1 and LDO2. EN2 can independently be used to enable Buck2. Figure 6 illustrates the power UP/DOWN timing sequence of the LP3905 blocks for  $V_{EN} \geq V_{IH (min)}$  (enable) and  $V_{EN} \leq V_{IL (max)}$  (disable).

Both linear regulators have active pulldowns when the outputs are disabled.



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EN1 and EN2 can be controlled fully independently.

LDOs will be turned on only after Buck1 is powered up. LDOs are powered on simultaneously.

In case EN1 and EN2 are enabled at the same time, power up of Buck2 is delayed by 50μs in order to minimize the inrush current from the battery.

When EN1 and EN2 are disabled, the relevant output voltages are turned off.

FIGURE 6. LP3905 Power UP/DOWN Timing Sequence



## Functional Description (Continued)

### DC/DC BUCK REGULATORS

The LP3905 Buck regulators are high efficiency step down DC-DC switching converters used for delivering a constant voltage from either a single Li-Ion or three cell NiMH/NiCd battery to portable devices such as cell phones and PDAs. Using a voltage mode architecture with synchronous rectification, the Buck Regulators have the ability to deliver up to 600 mA depending on the input voltage, output voltage, ambient temperature and the inductor chosen.

There are three modes of operation depending on the current required - PWM, PFM, and shutdown. The standard device operates in PWM mode at load currents of approximately 80 mA or higher, having voltage tolerance of  $\pm 4\%$  with 90% efficiency or better. Lighter load currents cause the device to automatically switch into PFM for reduced current

consumption and a longer battery life. Shutdown mode turns off the device, offering the lowest current consumption. A fixed mode device is also available which is fixed in PWM mode for both low and high load currents.

An adjustable voltage version is also available for which the output voltage can be selected by using two external resistors at each of the two buck outputs.

Additional features include soft-start, under voltage protection, current overload protection, and thermal shutdown protection.

The part uses an internal reference voltage of 0.5V. It is recommended to keep the part in shutdown until the input voltage is 3V or higher.

### BUCK CONVERTER BLOCK DIAGRAM

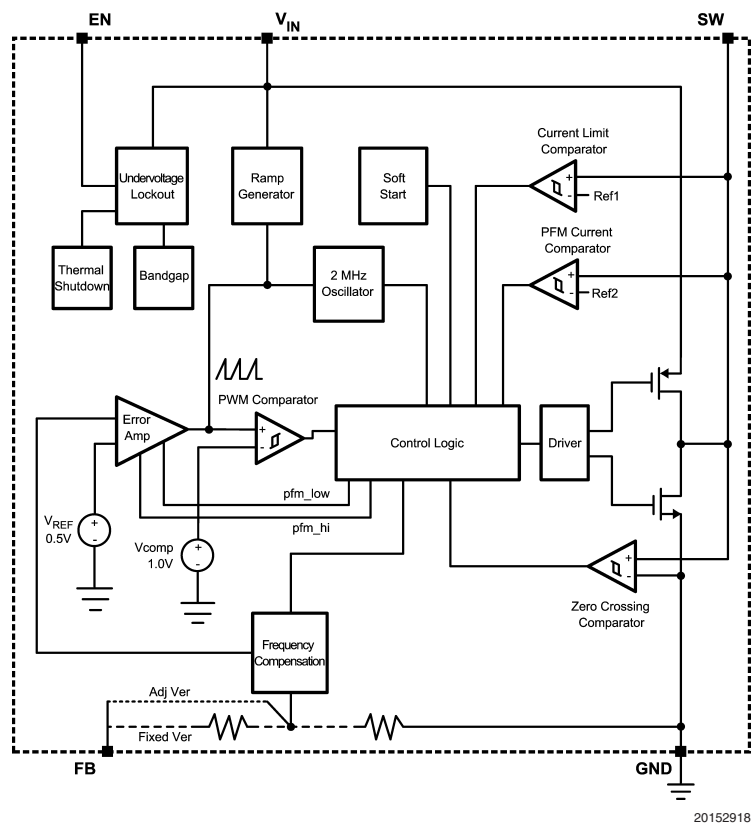


FIGURE 7. Simplified Functional Diagram

### CIRCUIT OPERATION

The LP3905 Buck regulators operate as follows. During the first portion of each switching cycle, the control block in the LP3905 turns on the internal PFET switch. This allows current to flow from the input through the inductor to the output filter capacitor and load. The inductor limits the current to a ramp with a slope of  $(V_{IN}-V_{OUT})/L$ , by storing energy in a magnetic field.

During the second portion of each cycle, the controller turns the PFET switch off, blocking current flow from the input, and then turns the NFET synchronous rectifier on. The inductor

draws current from ground through the NFET to the output filter capacitor and load, which ramps the inductor current down with a slope of  $-V_{OUT}/L$ .

The output filter stores charge when the inductor current is high, and releases it when inductor current is low, smoothing the voltage across the load.

The output voltage is regulated by modulating the PFET switch on time to control the average current sent to the load. The effect is identical to sending a duty-cycle modulated rectangular wave formed by the switch and synchronous

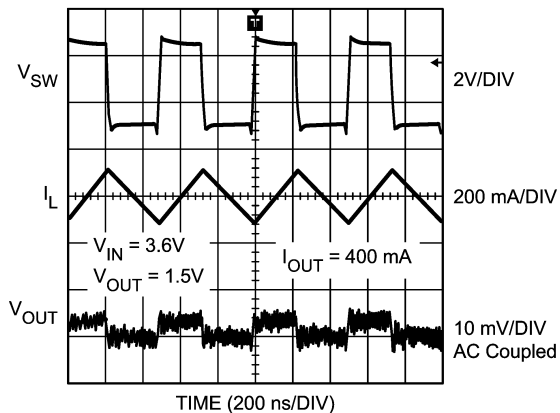
## Functional Description (Continued)

rectifier at the SW pin to a low-pass filter formed by the inductor and output filter capacitor. The output voltage is equal to the average voltage at the SW pin.

### PWM OPERATION

During PWM operation the converters operate as a voltage-mode controllers with input voltage feed forward. This allows the converters to achieve good load and line regulation. The DC gain of the power stage is proportional to the input voltage. To eliminate this dependence, feed forward inversely proportional to the input voltage is introduced.

While in PWM (Pulse Width Modulation) mode, the output voltage is regulated by switching at a constant frequency and then modulating the energy per cycle to control power to the load. At the beginning of each clock cycle the PFET switch is turned on and the inductor current ramps up until the comparator trips and the control logic turns off the switch. The current limit comparator can also turn off the switch in case the current limit of the PFET is exceeded. Then the NFET switch is turned on and the inductor current ramps down. The next cycle is initiated by the clock turning off the NFET and turning on the PFET.



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FIGURE 8. Typical PWM Operation

### Internal Synchronous Rectification

While in PWM mode, if enabled, the Bucks use an internal NFET as a synchronous rectifier to reduce rectifier forward voltage drop and associated power loss. Synchronous rectification provides a significant improvement in efficiency whenever the output voltage is relatively low compared to the voltage drop across an ordinary rectifier diode.

### Current Limiting

A current limit feature allows the LP3905 Bucks to protect Internal and external components during overload conditions. PWM mode implements current limiting using an internal comparator that trips at 1000 mA (typ). If the output is shorted to ground the device enters a timed current limit mode where the NFET is turned on for a longer duration until the inductor current falls below a low threshold, ensuring inductor current has more time to decay, thereby preventing runaway.

### PFM OPERATION

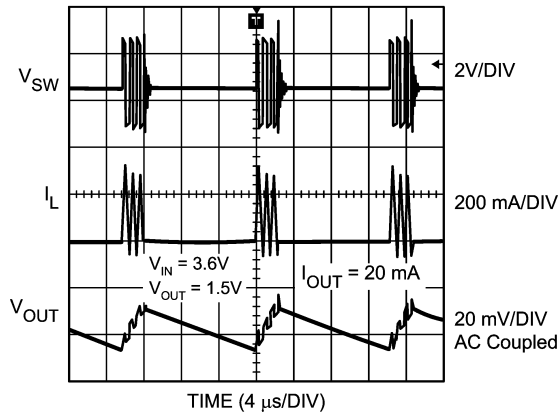
At very light loads, the converters enters PFM mode and operate with reduced switching frequency and supply current to maintain high efficiency.

The Bucks will automatically transition into PFM mode when either of two conditions occurs for a duration of 32 or more clock cycles:

- The inductor current becomes discontinuous.
- The peak PMOS switch current drops below the  $I_{MODE}$  level,

$$\text{Typically } I_{MODE} < 30 \text{ mA} + \frac{V_{IN}}{42\Omega}$$

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FIGURE 9. Typical PFM Operation

During PFM operation, the converter positions the output voltage slightly higher than the nominal output voltage during PWM operation, allowing additional headroom for voltage drop during a load transient from light to heavy load. The PFM comparators sense the output voltage via the feedback pin and control the switching of the output FETs such that the output voltage ramps between  $\sim 0.6\%$  and  $\sim 1.7\%$  above the nominal PWM output voltage. If the output voltage is below the 'high' PFM comparator threshold, the PMOS power switch is turned on. It remains on until the output voltage reaches the 'high' PFM threshold or the peak current exceeds the  $I_{PFM}$  level set for PFM mode. The typical peak current in PFM mode is:

$$I_{PFM} = 112 \text{ mA} + \frac{V_{IN}}{27\Omega}$$

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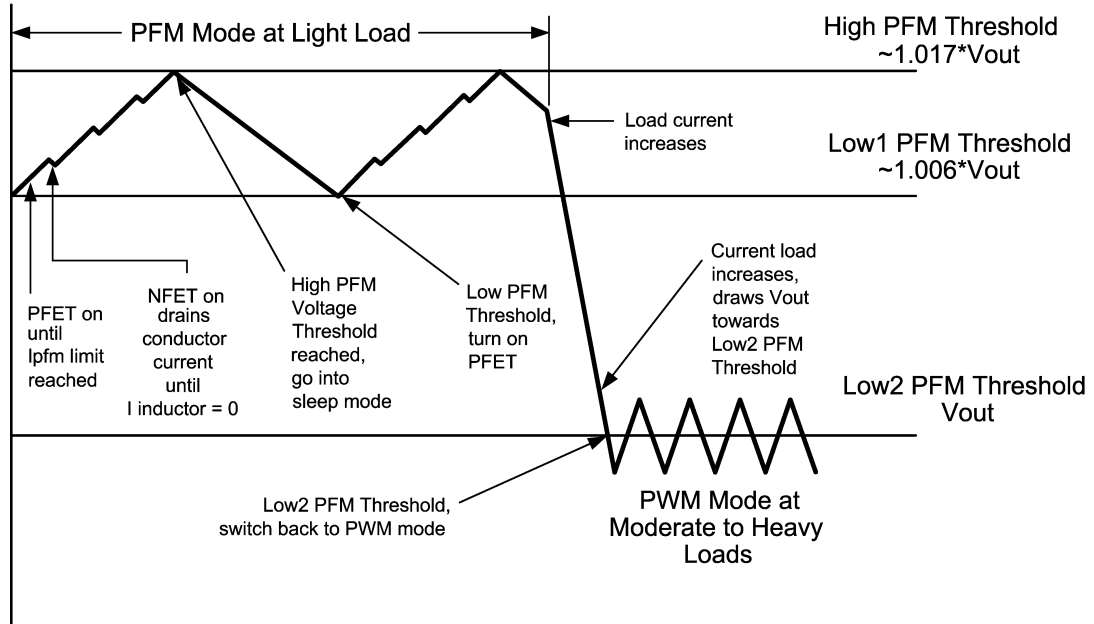
Once the PMOS power switch is turned off, the NMOS power switch is turned on until the inductor current ramps to zero. When the NMOS zero-current condition is detected, the NMOS power switch is turned off. If the output voltage is below the 'high' PFM comparator threshold, the PMOS switch is again turned on and the cycle is repeated until the output reaches the desired level. Once the output reaches the 'high' PFM threshold, the NMOS switch is turned on briefly to ramp the inductor current to zero and then both output switches are turned off and the part enters an extremely low power mode. Quiescent supply current during this 'sleep' mode is  $16\mu\text{A}$  (typ), which allows the part to achieve high efficiencies under extremely light load conditions. When the output drops below the 'low' PFM threshold,

## Functional Description (Continued)

the cycle repeats to restore the output voltage (average voltage in pfm mode) to  $\sim 1.15\%$  above the nominal PWM output voltage.

If the load current should increase during PFM mode causing the output voltage to fall below the 'low2' PFM threshold, the part will automatically transition into fixed-frequency

PWM mode. When  $V_{IN} = 2.8V$  the part transitions from PWM to PFM mode at  $\sim 35mA$  output current and from PFM to PWM mode at  $\sim 85mA$ , when  $V_{IN} = 3.6V$ , PWM to PFM transition happens at  $\sim 50mA$  and PFM to PWM transition happens at  $\sim 100mA$ , when  $V_{IN} = 4.5V$ , PWM to PFM transition happens at  $\sim 65mA$  and PFM to PWM transition happens at  $\sim 115mA$ .



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FIGURE 10. Operation in PFM Mode and Transfer to PWM Mode

### SOFT START

The LP3905 Buck Converters have a soft-start circuit that limits in-rush current during start-up. Additionally, in case EN1 and EN2 are enabled at the same time, a typical  $500\mu s$  delay between Buck1 and Buck2 Power Up prevents any further inrush current from the battery.

During start-up the switch current limit is increased in steps. Soft start is activated only if EN goes from logic low to logic

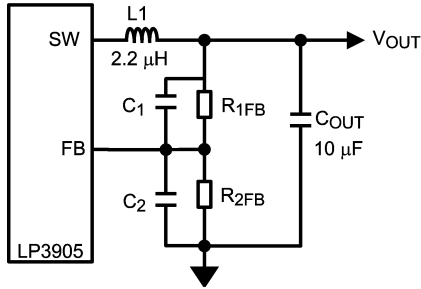
high after  $V_{in}$  reaches  $3V$ . Soft start is implemented by increasing switch current limit in steps of  $70mA$ ,  $140mA$ ,  $280mA$  and  $1000mA$  (typ. switch current limit). The start-up time thereby depends on the output capacitor and load current demanded at start-up. Typical start-up times with  $22\mu F$  output capacitor and  $300mA$  load current is  $400\mu s$  and with  $1mA$  load current its  $275\mu s$ .

# Application Information

## DC/DC CONVERTERS

### Adjustable Buck - Output Voltage Selection

The buck converter output voltage of the adjustable version device can be set via the selection of the external feedback resistor network forming the output feedback between the output voltage side of the Inductor and the FB pin and the FB Pin and GND.



Adjustable Buck Converter Components

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$V_{OUT}$  will be adjusted to make the voltage at FB equal to 0.5V. The resistor from FB to ground ( $R_{FB2}$ ) should be

around 200kΩ to keep the current drawn through the resistor network well below the 16μA quiescent current level (PFM mode) but large enough that it is not susceptible to noise. If  $R_2$  is 200kΩ and with  $V_{FB}$  at 0.5V, the current through the resistor feedback network will be 2.5μA.

The formula for output voltage selection is

$$V_{OUT} = V_{FB} \times \left(1 + \frac{R_{1FB}}{R_{2FB}}\right)$$

$V_{OUT}$  - output voltage (Volts)

$V_{FB}$  - feedback voltage (0.5V)

$R_{1FB}$  - feedback resistor from  $V_{OUT}$  to FB

$R_{2FB}$  - feedback resistor from FB to GND

For any out voltage greater than or equal to 1.0V a zero should be added around 45 kHz by the addition of a capacitor C1. The formula for the calculation of C1 is:

$$C_1 = \frac{1}{(2 \times \pi \times R_{1FB} \times 45 \times 10^3)}$$

For recommended component values see *Table 1*

TABLE 1. Buck Component Configurations for Various Output Voltage Values

$V_{OUT}$ (V)	RFB1 (kΩ)	RFB2 (kΩ)	C1 (pF)	C2 (pF)	L (μH)	$C_{OUT}$ (μF)
1.0	200	200	18	none	2.2	10
1.2	280	200	12	none	2.2	10
1.4	360	200	10	none	2.2	10
1.5	360	180	10	none	2.2	10
1.6	442	200	8.2	none	2.2	10
1.85	540	200	6.8	none	2.2	10
2.5	402	100	8.2	none	2.2	10
2.8	464	100	8.2	33	2.2	10
3.3	562	100	6.8	33	2.2	10

### Buck Inductor Selection

There are two main considerations when choosing an inductor; the inductor should not saturate, and the inductor current ripple is small enough to achieve the desired output voltage ripple. Different saturation current rating specs are followed by different manufacturers so attention must be given to details. Saturation current ratings are typically specified at 25°C so ratings at max ambient temperature of application should be requested from manufacturer.

There are two methods to choose the inductor saturation current rating.

#### Method 1:

The saturation current is greater than the sum of the maximum load current and the worst case average to peak inductor current. This can be written as

$$I_{SAT} > I_{OUTMAX} + I_{RIPPLE}$$

$$\text{where } I_{RIPPLE} = \left(\frac{V_{IN} - V_{OUT}}{2 * L}\right) * \left(\frac{V_{OUT}}{V_{IN}}\right) * \left(\frac{1}{f}\right)$$

- $I_{RIPPLE}$ : average to peak inductor current

- $I_{OUTMAX}$ : maximum load current (600mA)
- $V_{IN}$ : maximum input voltage in application
- L : min inductor value including worst case tolerances (30% drop can be considered for method 1)
- f : minimum switching frequency (1.6Mhz)
- $V_{OUT}$ : output voltage

#### Method 2:

A more conservative and recommended approach is to choose an inductor that has saturation current rating greater than the max current limit of 1220mA.

A 2.2μH inductor with a saturation current rating of at least 1250mA is recommended for most applications. The inductor's resistance should be less than 0.3Ω for good efficiency. For low-cost applications, an unshielded bobbin inductor could be considered. For noise critical applications, a toroidal or shielded-bobbin inductor should be used. A good practice is to lay out the board with overlapping footprints of both types for design flexibility. This allows substitution of a low-noise shielded inductor, in the event that noise from low-cost bobbin models is unacceptable.

## Application Information (Continued)

### Buck DC/DC Convertor Input Capacitor Selection

A ceramic input capacitor of 10 $\mu$ F, 6.3V is sufficient for most applications. Place the input capacitor as close as possible to the  $V_{IN}$  pin of the device. A larger value may be used for improved input voltage filtering. Use X7R or X5R types, do not use Y5V. DC bias characteristics of ceramic capacitors must be considered when selecting case sizes like 0805 and 0603. The input filter capacitor supplies current to the PFET switch of the LP3905 in the first half of each cycle and reduces voltage ripple imposed on the input power source. A ceramic capacitor's low ESR provides the best noise filtering of the input voltage spikes due to this rapidly changing current. Select a capacitor with sufficient ripple current rating. The input current ripple can be calculated as:

$$I_{RMS} = I_{OUTMAX} * \sqrt{\frac{V_{OUT}}{V_{IN}} * \left(1 - \frac{V_{OUT}}{V_{IN}} + \frac{r^2}{12}\right)}$$

$$r = \frac{(V_{IN} - V_{OUT}) * V_{OUT}}{L * f * I_{OUTMAX} * V_{IN}}$$

The worst case is when  $V_{IN} = 2 * V_{OUT}$

### DC/DC CONVERTOR OUTPUT CAPACITOR SELECTION

Use a 10 $\mu$ F, 6.3V ceramic capacitor. Use X7R or X5R types, do not use Y5V. DC bias characteristics of ceramic capacitors must be considered when selecting case sizes like 0805 and 0603. DC bias characteristics vary from manufacturer to manufacturer and dc bias curves should be requested from them as part of the capacitor selection process.

The output filter capacitor smoothes out current flow from the inductor to the load, helps maintain a steady output voltage during transient load changes and reduces output voltage ripple. These capacitors must be selected with sufficient capacitance and sufficiently low ESR to perform these functions.

The output voltage ripple is caused by the charging and discharging of the output capacitor and also due to its  $R_{ESR}$  and can be calculated as:

Voltage peak-to-peak ripple due to capacitance can be expressed as follows

$$V_{PP-C} = \frac{I_{RIPPLE}}{4 * f * C}$$

Voltage peak-to-peak ripple due to ESR can be expressed as follows

$$V_{PP-ESR} = (2 * I_{RIPPLE}) * R_{ESR}$$

Because these two components are out of phase the rms value can be used to get an approximate value of peak-to-peak ripple.

Voltage peak-to-peak ripple, root mean squared can be expressed as follows

$$V_{PP-RMS} = \sqrt{V_{PP-C}^2 + V_{PP-ESR}^2}$$

Note that the output voltage ripple is dependent on the inductor current ripple and the equivalent series resistance of the output capacitor ( $R_{ESR}$ ).

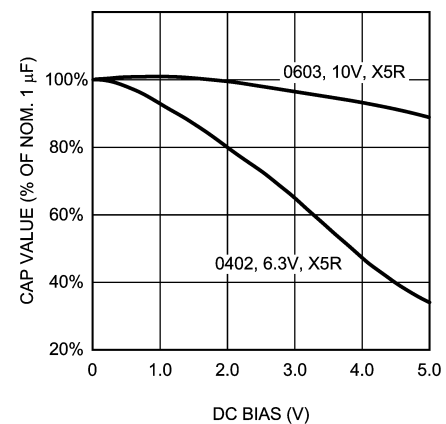
The  $R_{ESR}$  is frequency dependent (as well as temperature dependent); make sure the value used for calculations is at the switching frequency of the part.

## LINEAR REGULATORS

### Capacitor Selection

The LP3955 is designed to work with ceramic capacitors on the output to take advantage of the benefits they offer: for capacitance values in the range of 0.47 $\mu$ F to 10 $\mu$ F range, ceramic capacitors are the smallest, least expensive and have the lowest ESR values (which makes them best for eliminating high frequency noise). The ESR of a typical 1 $\mu$ F ceramic capacitor is in the range of 20m $\Omega$  to 40m $\Omega$ , which easily meets the ESR requirement for stability by the LP3955. For both input and output capacitors careful interpretation of the capacitor specification is required to ensure correct device operation. The capacitor value can change greatly dependant on the conditions of operation and capacitor type.

In particular the output capacitor selection should take account of all the capacitor parameters to ensure that the specification is met within the application. Capacitance value can vary with DC bias conditions as well as temperature and frequency of operation. Capacitor values will also show some decrease over time due to aging. The capacitor parameters are also dependant on the particular case size with smaller sizes giving poorer performance figures in general. As an example *Figure 11* shows a typical graph showing a comparison of capacitor case sizes in a Capacitance vs. DC Bias plot. As shown in the graph, as a result of the DC Bias condition the capacitance value may drop below the minimum capacitance value given in the recommended capacitor table (0.7 $\mu$ F in this case). Note that the graph shows the capacitance out of spec for the 0402 case size capacitor at higher bias voltages. It is therefore recommended that the capacitor manufacturers' specifications for the nominal value capacitor are consulted for all conditions as some capacitor sizes (e.g. 0402) may not be suitable in the actual application.



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FIGURE 11. Capacitor Performance (DC Bias)

## Application Information (Continued)

The ceramic capacitor's capacitance can vary with temperature. The capacitor type X7R, which operates over a temperature range of  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ , will only vary the capacitance to within  $\pm 15\%$ . The capacitor type X5R has a similar tolerance over a reduced temperature range of  $-55^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ .

Tantalum capacitors are less desirable than ceramic for use as output capacitors because they are more expensive when comparing equivalent capacitance and voltage ratings in the  $1\mu\text{F}$  to  $4.7\mu\text{F}$  range.

Another important consideration is that tantalum capacitors have higher ESR values than equivalent size ceramics. This means that while it may be possible to find a tantalum capacitor with an ESR value within the stable range, it would have to be larger in capacitance (which means bigger and more costly) than a ceramic capacitor with the same ESR value. It should also be noted that the ESR of a typical tantalum will increase about 2:1 as the temperature goes from  $25^{\circ}\text{C}$  down to  $-40^{\circ}\text{C}$ , so some guard band must be allowed.

### LDO Input Capacitor

An input capacitor is required for stability. The input capacitor should be at least equal to or greater than the output capacitor. It is recommended that a  $1\mu\text{F}$  capacitor be connected between  $V_{\text{IN}2}$  input pin and ground (this capacitance value may be increased without limit).

This capacitor must be located a distance of not more than 1cm from the input pin and returned to a clean analogue ground. Any good quality ceramic, tantalum, or film capacitor may be used at the input.

**Important:** Tantalum capacitors can suffer catastrophic failures due to surge current when connected to a low-impedance source of power (like a battery or a very large capacitor). If a tantalum capacitor is used at the input, it must

be guaranteed by the manufacturer to have a surge current rating sufficient for the application. There are no requirements for the ESR (Equivalent Series Resistance) on the input capacitor, but tolerance and temperature coefficient must be considered when selecting the capacitor to ensure the capacitance will remain  $1.0\mu\text{F} \pm 30\%$  over the entire operating voltage and temperature range.

### LDO Output Capacitor

The LP3905 LDOs are designed specifically to work with very small ceramic output capacitors. A ceramic capacitor (dielectric types X5R or X7R) in the  $0.47\mu\text{F}$  to  $10\mu\text{F}$  range, and with ESR between  $5\text{m}\Omega$  to  $500\text{m}\Omega$ , is suitable in the application circuit. For this device the output capacitor should be connected between the LDO1 and LDO2 pins and a good ground connection and should be mounted within 1cm of the device.

The output capacitor must meet the requirement for the minimum value of capacitance and also have an ESR value that is within the range  $5\text{m}\Omega$  to  $500\text{m}\Omega$  for stability.

### No-Load Stability

The LP3905 LDOs will remain stable and in regulation with no external load.

### Enable Control

A  $1\text{M}\Omega$  pulldown resistor ties the  $\text{EN}_{1/2}$  input to ground, this ensures that the device will remain off when the enable pin is left open circuit. To ensure proper operation, the signal source used to drive the  $\text{EN}_{1/2}$  input must be able to swing above and below the specified turn-on/off voltage thresholds listed in the Electrical Characteristics section under  $V_{\text{IL}}$  and  $V_{\text{IH}}$ . EN1 can be used to turn ON Buck1 and LDO1/2. In this case Buck1 will be turned on first. Once Buck1 is powered up, after a typical  $150\mu\text{s}$  delay LDO1/2 will be turned on concurrently.

## LP3905 Board Layout Considerations

PC board layout is an important part of DC-DC converter design. Poor board layout can disrupt the performance of a DC-DC converter and surrounding circuitry by contributing to EMI, ground bounce, and resistive voltage loss in the traces. These can send erroneous signals to the DC-DC converter IC, resulting in poor regulation or instability.

Good layout for the LP3905 can be implemented by following a few simple design rules.

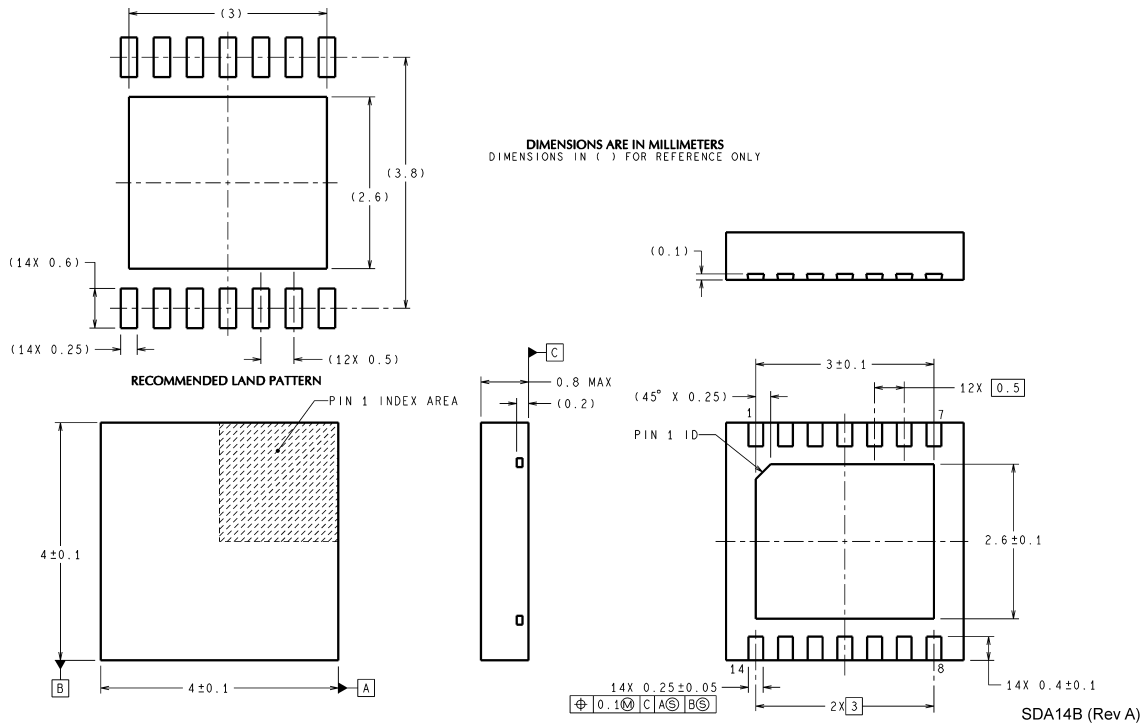
1. *Place the Buck inductor and filter capacitors close together and make the traces short.* The traces between these components carry relatively high switching currents and act as antennas. Following this rule reduces radiated noise. Special care must be given to place the input filter capacitor very close to the  $V_{IN}$  and GND pin.
2. *Arrange the components so that the switching current loops curl in the same direction.* During the first half of each cycle, current flows from the input filter capacitor through the LP3905 and inductor to the output filter capacitor and back through ground, forming a current loop. In the second half of each cycle, current is pulled up from ground through the LP3905 by the inductor to the output filter capacitor and then back through ground forming a second current loop. Routing these loops so the current curls in the same direction prevents magnetic field reversal between the two half-cycles and reduces radiated noise.
3. *Connect the ground pins of the Bucks and filter capacitors together using generous component-side copper fill as a pseudo-ground plane. Then, connect this to the ground-plane (if one is used) with several vias.* This

reduces ground-plane noise by preventing the switching currents from circulating through the ground plane. It also reduces ground bounce at the LP3905 by giving it a low-impedance ground connection.

4. *Use wide traces between the power components and for power connections to the DC-DC converter circuit.* This reduces voltage errors caused by resistive losses across the traces.
5. *Route noise sensitive traces, such as the voltage feedback path, away from noisy traces between the power components.* The voltage feedback trace must remain close to the Buck circuits and should be direct but should be routed opposite to noisy components. This reduces EMI radiated onto the DC-DC converter's own voltage feedback trace. A good approach is to route the feedback trace on another layer and to have a ground plane between the top layer and layer on which the feedback trace is routed. In the same manner for the adjustable part it is desired to have the feedback dividers on the bottom layer.
6. *Place noise sensitive circuitry, such as radio IF blocks, away from the DC-DC converter, CMOS digital blocks and other noisy circuitry.* Interference with noise-sensitive circuitry in the system can be reduced through distance.

In mobile phones, for example, a common practice is to place the DC-DC converters on one corner of the board, arrange the CMOS digital circuitry around it (since this also generates noise), and then place sensitive preamplifiers and IF stages on the diagonally opposing corner. Often, the sensitive circuitry is shielded with a metal pan and power to it is post-regulated to reduce conducted noise, using low-dropout linear regulators.

**Physical Dimensions** inches (millimeters) unless otherwise noted



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