100mA Wireless Li-Ion Charger with Low Battery Disconnect

FEATURES

- **Complete Wireless Power Receiver, Li-Ion Charger and PowerPath™ Controller**
- **Wireless Input Power Control and Rectification**
- **Wideband Wireless Power Frequency: DC to >10MHz**
- Pin-Selectable Charge Current: 10mA/25mA/50mA/100mA
- Pin-Selectable Charge Voltage: 4.0V/4.1V/4.2V/4.35V
- Pin-Selectable Low Battery Disconnect: 2.7V/3.2V
- **Zero Battery Drain Current in Disconnect/Ship Mode**
- Pin-Selectable Low Battery Pre-Charge Current Enable
- NTC Input for Temperature Qualified Charging
- Safety Charge Termination Timer
- **Tiny Total Solution Size with Few Externals**
- Small Thermally Enhanced 12-lead 2mm × 2mm LQFN Package

APPLICATIONS

- Medical Wireless Sensors
- Military Wearables
- High End Wireless Headsets
- Streaming Headsets with Bluetooth Connectivity
- Virtual Reality Headsets
- High End Remote Control
- IoT Devices

DESCRIPTION

The LTC®4124 is a simple high performance wireless Li-Ion charger with low battery disconnect. The pin-selectable charge current (up to 100mA) and charge voltage ensure versatility while minimizing the number of required external components.

Wireless charging with the LTC4124 allows devices to be charged while sealed within enclosures and eliminates bulky connectors in space-constrained applications. Elimination of exposed conductive connectors also creates more robust devices while ensuring an effortless end-user experience.

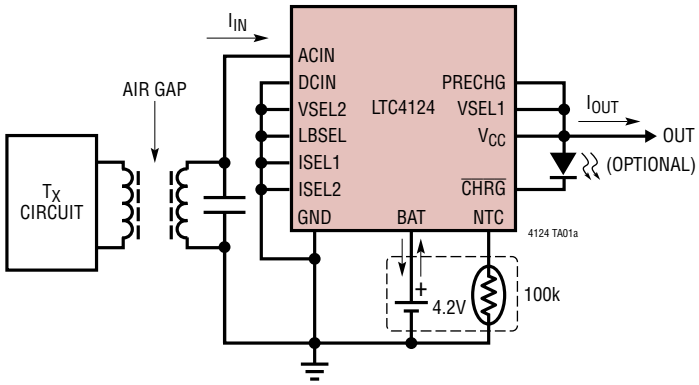
The LTC4124 includes an NTC input for safe temperature qualified charging and a battery disconnect feature that prevents damage to a battery due to over-discharging.

The 2mm × 2mm LQFN package and minimal number of external components make the LTC4124 well-suited for low power portable applications where small solution size is mandatory.

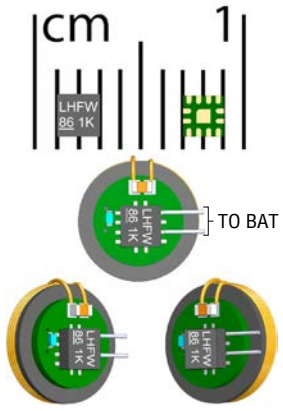
All registered trademarks and trademarks are the property of their respective owners.

TYPICAL APPLICATION

10mA Wireless 4.2V Li-Ion Charger with 1mA Pre-Charge Conditioning and 2.7V Low Battery Disconnect



Top and Bottom View of the IC with Complete Application Circuit Boards



Rev. A

ABSOLUTE MAXIMUM RATINGS

(Notes 1, 2)

Input Supply Voltages
- DCIN, V_{CC}, BAT ..... –0.3V to 6V
- ACIN ..... V_{CC} – 40V to V_{CC} + 0.3V

Input Supply Currents
- I(ACIN) 200mA
- I(DCIN) 200mA

$\overline{CHRG}$ ..... –0.3V to V_{CC} + 0.3V

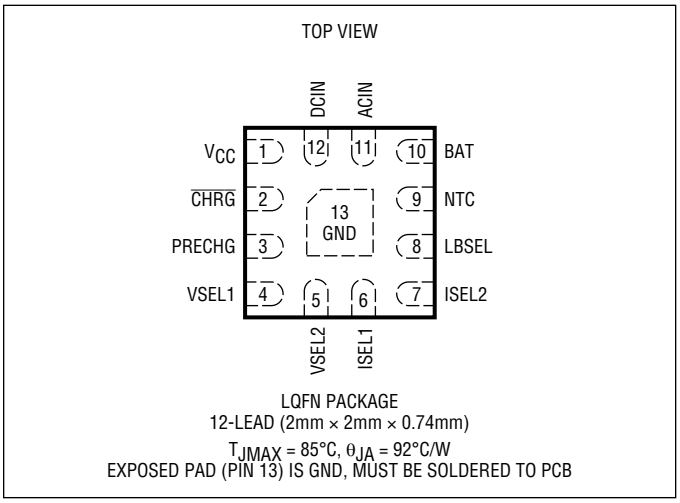
Programming Pins
- VSEL1, VSEL2, ISEL1, ISEL2 ..... –0.3V to V_{CC} + 0.3V
- NTC, LBSEL, PRECHG ..... –0.3V to V_{CC} + 0.3V

Operating Junction Temperature Range (Note 3) ..... –20°C to 85°C

Storage Temperature Range ..... –40°C to 125°C

Maximum Reflow (Package Body) Temperature ..... 260°C

PIN CONFIGURATION



LQFN PACKAGE
12-LEAD (2mm × 2mm × 0.74mm)
T_{JMAX} = 85°C, θ_{JA} = 92°C/W
EXPOSED PAD (PIN 13) IS GND, MUST BE SOLDERED TO PCB

ORDER INFORMATION

PART NUMBER	PART MARKING*	FINISH CODE	PAD FINISH	PACKAGE** TYPE	MSL RATING	TEMPERATURE RANGE
LTC4124EV#TRPBF	LHFW	e4	Au (RoHS)	LQFN (Laminate Package with QFN Footprint)	3	–20°C to 85°C
LTC4124EV#TRMPBF	LHFW	e4	Au (RoHS)	LQFN (Laminate Package with QFN Footprint)	3	–20°C to 85°C

- Contact the factory for parts specified with wider operating temperature ranges. *Device temperature grade is identified by a label on the shipping container.
- Pad finish code is per IPC/JEDEC J-STD-609.
- Recommended LGA and BGA PCB Assembly and Manufacturing Procedures
- LGA and BGA Package and Tray Drawings

Parts ending with PBF are RoHS and WEEE compliant. **The LTC4124 package has the same dimensions as a standard 2mm × 2mm × 0.74mm QFN Package.

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the specified operating junction temperature range, otherwise specifications are at T_A = 25°C. V_{CC} = 5V unless otherwise noted (Notes 2, 3).

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{DCIN}	DC Input Supply Operating Range		●	3.3		5.5	V
V_{CC}	Supply Operating Range		●	2.7		5.5	V
I_{VCC}	Input Quiescent Current	V_{CC} = 5V, Not Charging	●		120	250	µA
I_{BAT}	Battery Quiescent Current	Done Charging or Not Charging, $V_{CC} > V_{BAT}$	●		3.5	7	µA
		Ideal Diode Mode, ACIN = DCIN = 0V, NTC = V_{CC} or Open	 ●		8 8	15 80	µA µA
		Ideal Diode Mode, ACIN = DCIN = 0V, NTC = 100kΩ to GND	 ●		28 28	35 100	µA µA
		Disconnect Mode, $V_{BAT} < V_{BAT_LBDIS}$, ACIN = DCIN = V_{CC} = 0V	●		0	50	nA
		Ship Mode, at any V_{BAT} Voltage Level, ACIN = DCIN = V_{CC} = 0V	●		0	50	nA
Wireless and DC Power Management							
$\Delta V_{CC(HIGH)}$	V_{CC} High Voltage Limit above V_{BAT}	V_{CC} Rising, V_{BAT} = 3.6V			1.05		V
$\Delta V_{CC(LOW)}$	V_{CC} Low Voltage Limit above V_{BAT}	V_{CC} Falling, V_{BAT} = 3.6V			0.85		V
	ACIN to V_{CC} Voltage Drop	V_{ACIN} = 5V, V_{DCIN} = 0V, I_{VCC} = –100mA, Not Charging			0.45		V
	DCIN to V_{CC} Voltage Drop	V_{DCIN} = 5V, V_{ACIN} = 0V, I_{VCC} = –100mA, Not Charging			0.45		V
Battery Charging							
V_{UVCL}	V_{CC} Undervoltage Current Limit Regulation Point	$I_{SEL1} = I_{SEL2} = V_{CC}$, I_{CHG} = 1mA (10%)			3.4		V
V_{UVCL_TH}	V_{CC} Fault Indicator Threshold into UVCL	V_{CC} Falling, V_{BAT} = 3.0V			3.45		V
	Hysteresis	V_{BAT} = 3.0V			50		mV
R_{CHG}	Charge Switch On Resistance	V_{BAT} = 3.6V			0.5		Ω
V_{BAT_REG}	Battery Charge Voltage	$V_{SEL1} = V_{SEL2} = V_{CC}$		4.339	4.350	4.361	V
			●	4.285	4.350	4.415	V
		$V_{SEL1} = V_{CC}$, V_{SEL2} = GND		4.190	4.200	4.210	V
			●	4.137	4.200	4.263	V
		V_{SEL1} = GND, $V_{SEL2} = V_{CC}$		4.090	4.100	4.110	V
			●	4.038	4.100	4.162	V
		$V_{SEL1} = V_{SEL2}$ = GND		3.990	4.000	4.010	V
			●	3.940	4.000	4.060	V
V_{BAT_RECHG}	Recharge Battery Threshold Voltage	V_{BAT} Falling, % of V_{BAT_REG}	●	96.0	97.6	98.6	%
	Hysteresis	% of V_{BAT_REG}			0.3		%
V_{BAT_TRKL}	Precharge Battery Voltage Threshold	V_{BAT} Rising, % of V_{BAT_REG}	●	65	68	71	%
	Hysteresis	% of V_{BAT_REG}			1		%
I_{CHG}	Charge Current in Constant Current Mode	ISEL1 = ISEL2 = V_{CC}	●	95	100	103.5	mA
		ISEL1 = V_{CC}, ISEL2 = GND	●	45	50	53.5	mA
		ISEL1 = GND, ISEL2 = V_{CC}	●	22	25	27.5	mA
		ISEL1 = ISEL2 = GND	●	8.5	10.0	11.5	mA
$I_{CHG(PRE)}$	Precharge Current	$V_{PRECHG} = V_{CC}$, % of I_{CHG}	●	6	10	14	%

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the specified operating junction temperature range, otherwise specifications are at T_A = 25°C. V_{CC} = 5V unless otherwise noted (Notes 2, 3).

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
$I_{C/10}$	C/10 Current Threshold in Constant Voltage Mode	I_{BAT} Falling, % of I_{CHG}			10		%
	Hysteresis				1		%
t_T	Charge Termination Time		●	2.2	3.0	4.0	hours
t_{BB}	Bad Battery Detection Time		●	30	45	60	mins
$V_{NTC(COLD)}$	NTC Cold Threshold	V_{NTC} Rising, % of V_{CC}	●	73	75	77	%
$V_{NTC(HOT)}$	NTC Hot Threshold	V_{NTC} Falling, % of V_{CC}	●	33	35	37	%
$V_{NTC(HYS)}$	NTC Thresholds Hysteresis	% of V_{CC}			5		%
$R_{NTC(OPEN)}$	NTC Open Circuit Input Resistance to V_{CC}	I_{NTC} = –25µA	●	98.5	100	101.5	kΩ
$V_{NTC(DIS)}$	NTC Disable Threshold	V_{NTC} Rising, % of V_{CC}	●	90	94	98	%
	Hysteresis	% of V_{CC}			5		%
Battery Discharging							
	Battery Discharge PowerPath Forward Regulation Voltage	$V_{BAT,VCC}$, I_{VCC} = –1mA, $V_{BAT} \geq V_{BAT_LBDIS}$		0	55	130	mV
	Battery PowerPath Forward Turn-On Threshold Voltage	$V_{BAT,VCC}$			100		mV
	Battery PowerPath Reverse Turn-Off Threshold Voltage	$V_{BAT,VCC}$, Not Charging			–100		mV
R_{DISCHG}	Discharge Switch On Resistance	V_{BAT} = 3.6V			0.5		Ω
	Maximum Battery Discharge Current Threshold for Safety Disconnect	V_{BAT} = 3.6V			1.0		A
Low Battery Disconnect							
V_{BAT_LBDIS}	Low Battery Disconnect Voltage	LBSEL = V_{CC}, V_{BAT} Falling	●	3.136	3.200	3.264	V
		LBSEL = GND, V_{BAT} Falling	●	2.646	2.700	2.754	V
$I_{BAT(LEAK)}$	Battery Leakage Current When Disconnected	$V_{BAT} < V_{BAT_LBDIS}$	●		0	50	nA
$\overline{CHRG}$ Status Pin							
$I_{\overline{CHRG}(LKG)}$	$\overline{CHRG}$ Open Drain Leakage Current	$V_{\overline{CHRG}}$ = 5V				1	µA
$I_{\overline{CHRG}}$	$\overline{CHRG}$ Pull Down Current	$V_{\overline{CHRG}}$ = 400mV		200	300	400	µA
$f_{BLINK(SLW)}$	Blink Slow Frequency			0.6	0.8	1.1	Hz
$f_{BLINK(FAST)}$	Blink Fast Frequency			4.5	6	8	Hz
Digital Input Pins (VSEL1, VSEL2, ISEL1, ISEL2, LBSEL, PRECHG)							
V_{IL}	Input Voltage Low		●	0.4			V
V_{IH}	Input Voltage High		●			V_{CC} – 0.4V	V
	Input Leakage Current	0V ≤ V_{PIN} ≤ V_{CC}	●	–1		1	µA

Note 1: Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

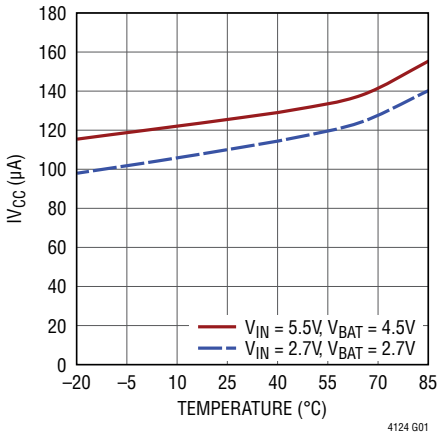
Note 2: All currents into pins are positive; all voltages are referenced to GND unless otherwise noted.

Note 3: The LTC4124 is tested under conditions such that $T_J \approx T_A$. The LTC4124E is guaranteed to meet specifications from 0°C to 85°C junction temperature. Specifications over the –20°C to 85°C operating junction temperature are assured by design, characterization and correlation with statistical process controls. Note that the maximum ambient temperature consistent with these specifications is determined by specific operating conditions in conjunction with board layout, the rated package thermal impedance and other environmental factors. The junction temperature (T_J, in °C) is calculated from the ambient temperature (T_A, in °C) and power dissipation (P_D, in Watts) according to the following formula:

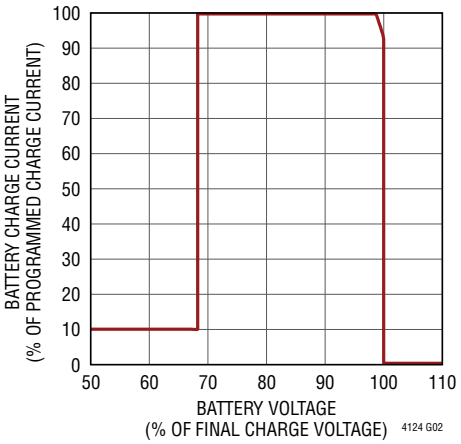
$T_J = T_A + (P_D \bullet \theta_{JA})$, where θ_{JA} (in °C/W) is the package thermal impedance.

TYPICAL PERFORMANCE CHARACTERISTICS T_A = 25°C, unless otherwise noted.

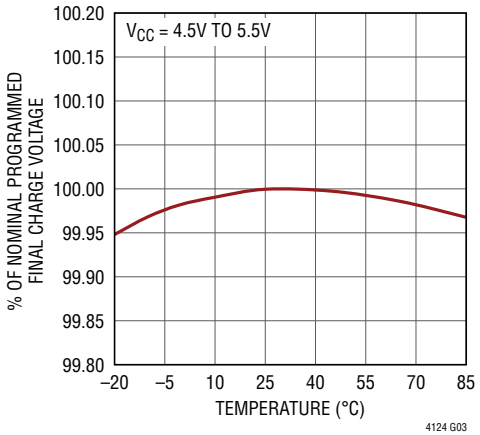
V_{CC} Supply Quiescent Current vs Temperature



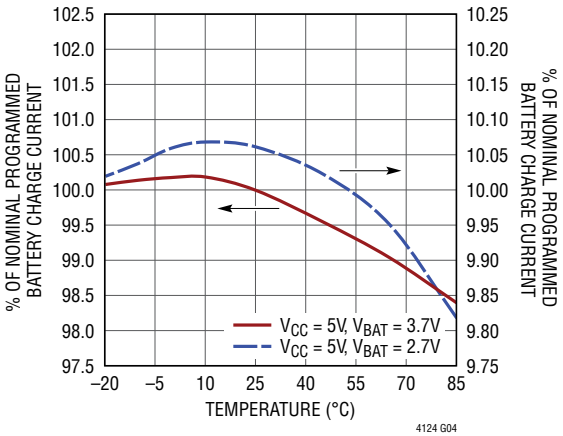
Battery Charge Current vs Battery Charge Voltage



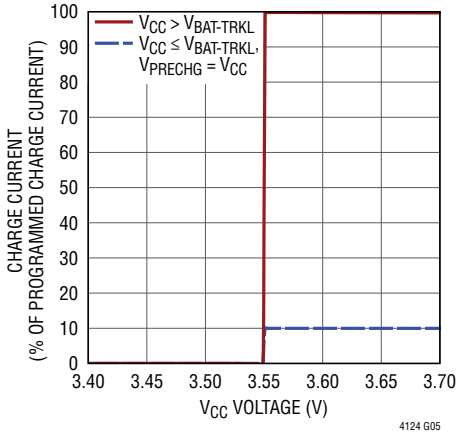
Battery Charge Voltage vs Temperature



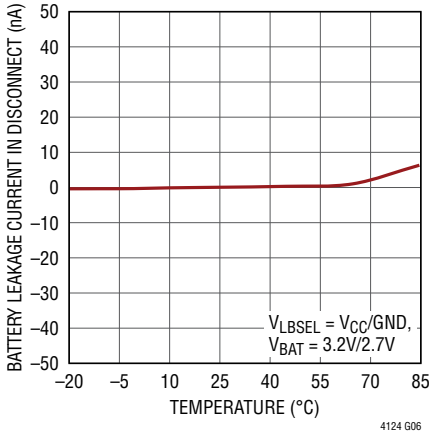
Normalized Battery Charge Current vs Temperature



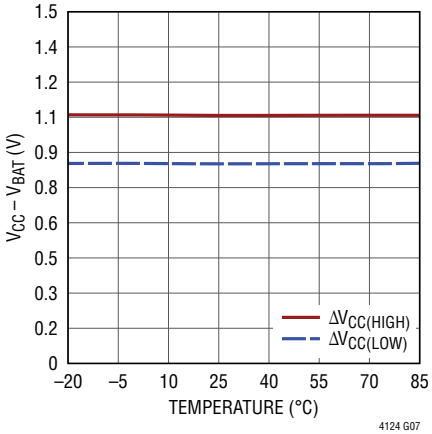
Undervoltage Current Limit: Charge Current vs V_{CC} Voltage



Disconnect Battery Leakage Current vs Temperature

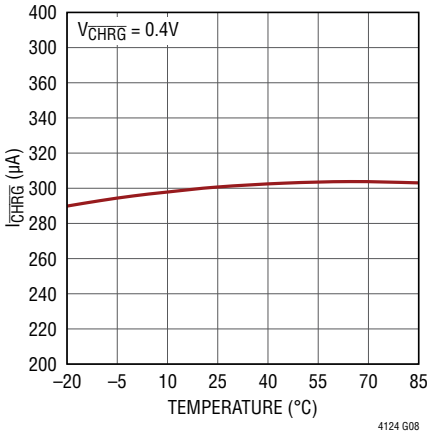


V_{CC} HIGH and LOW Limits above V_{BAT} vs Temperature

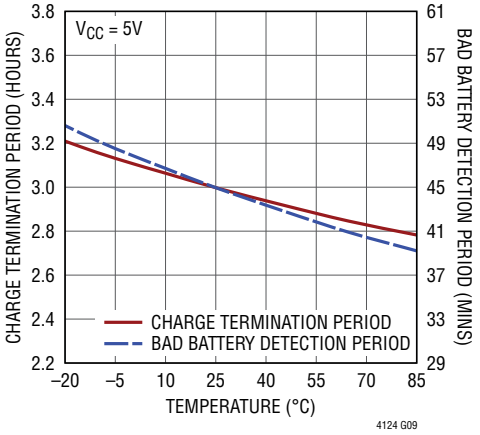


TYPICAL PERFORMANCE CHARACTERISTICS T_A = 25°C, unless otherwise noted.

$\overline{CHRG}$ Pull-Down Current vs Temperature



Charge Termination Period and Bad Battery Detection Period vs Temperature



PIN FUNCTIONS

V_{CC} (Pin 1): System DC Supply. The V_{CC} voltage range is 2.7V to 5.5V. An internal diode is connected from the ACIN pin (anode) to this pin (cathode), and a second one is connected from the DCIN pin (anode) to this pin (cathode). The voltage on this pin will be determined by the higher of the DCIN voltage and the peak AC voltage on the ACIN pin. There is an internal 2.2µF rectification capacitor connected between this pin and GND. Optional additional capacitance can be connected externally between this pin and GND.

$\overline{CHRG}$ (Pin 2): Charge Status Indicator. This pin is an open drain output with a 300µA current source pull down. In a typical application, this pin is pulled up by an LED to V_{CC}. This pin has four possible states shown in Table 1.

Table 1. $\overline{CHRG}$ States

$\overline{CHRG}$	Status
High Impedance	No Input Power
Blink Slow (0.8Hz)	Powered On and Charging
Blink Fast (6Hz)	Charging Paused due to Battery Temperature Out of Range, or
	Charging Stopped due to Bad Battery Detected, or
	Limited Charging due to Undervoltage Current Limit
Pull Down	End of Charge C/10 Reached or Charging Complete

PRECHG (Pin 3): Precharge Enable. Tie this pin to V_{CC} to enable low current precharge at battery voltages below the precharge battery threshold (V_{BAT_TRKL}). Tie this pin to GND to disable low current precharge. When low current precharge is disabled, full charge current will be delivered for battery voltages below the final charge voltage. Do not leave this pin open.

VSEL1 (Pin 4): Charge Voltage Select Bit 1. Tie this pin to V_{CC} or GND to program the battery charge voltage. Do not leave this pin open. Refer to Table 2 for programming the desired charge voltage.

VSEL2 (Pin 5): Charge Voltage Select Bit 2. Tie this pin to V_{CC} or GND to program the battery charge voltage. Do not leave this pin open. Refer to Table 2 for programming the desired charge voltage.

Table 2. Battery Charge Voltage Programming

VSEL1	VSEL2	Charge Voltage
High	High	4.35V
High	Low	4.20V
Low	High	4.10V
Low	Low	4.00V

PIN FUNCTIONS

ISEL1 (Pin 6): Charge Current Select Bit 1. Tie this pin to V_{CC} or GND to program the battery charge current. Do not leave this pin open. Refer to Table 3 for programming the desired charge current.

ISEL2 (Pin 7): Charge Current Select Bit 2. Tie this pin to V_{CC} or GND to program the battery charge current. Do not leave this pin open. Refer to Table 3 for programming the desired charge current.

Table 3. Battery Charge Current Programming

ISEL1	ISEL2	Charge Current
High	High	100mA
High	Low	50mA
Low	High	25mA
Low	Low	10mA

LBSEL (Pin 8): Low Battery Disconnect Voltage Select. Tie this pin to V_{CC} or GND to program the low battery disconnect voltage level. Do not leave this pin open. Refer to Table 4 for programming the desired low battery disconnect voltage level.

Table 4. Low Battery Disconnect Voltage Programming

LBSEL	Disconnect Voltage
High	3.2V
Low	2.7V

NTC (Pin 9): Thermistor Input. Connect a 100kΩ thermistor from NTC to GND. This pin is internally pulled up with a 100kΩ, 1% resistor to V_{CC}. The voltage level on this pin determines if the battery temperature is safe for charging. Charging and the charge timer are paused if the thermistor indicates temperature that is unsafe for charging. Once the temperature returns to the safe region, charging and the charge timer resume. Connect this pin to V_{CC} to disable the temperature qualified charging feature.

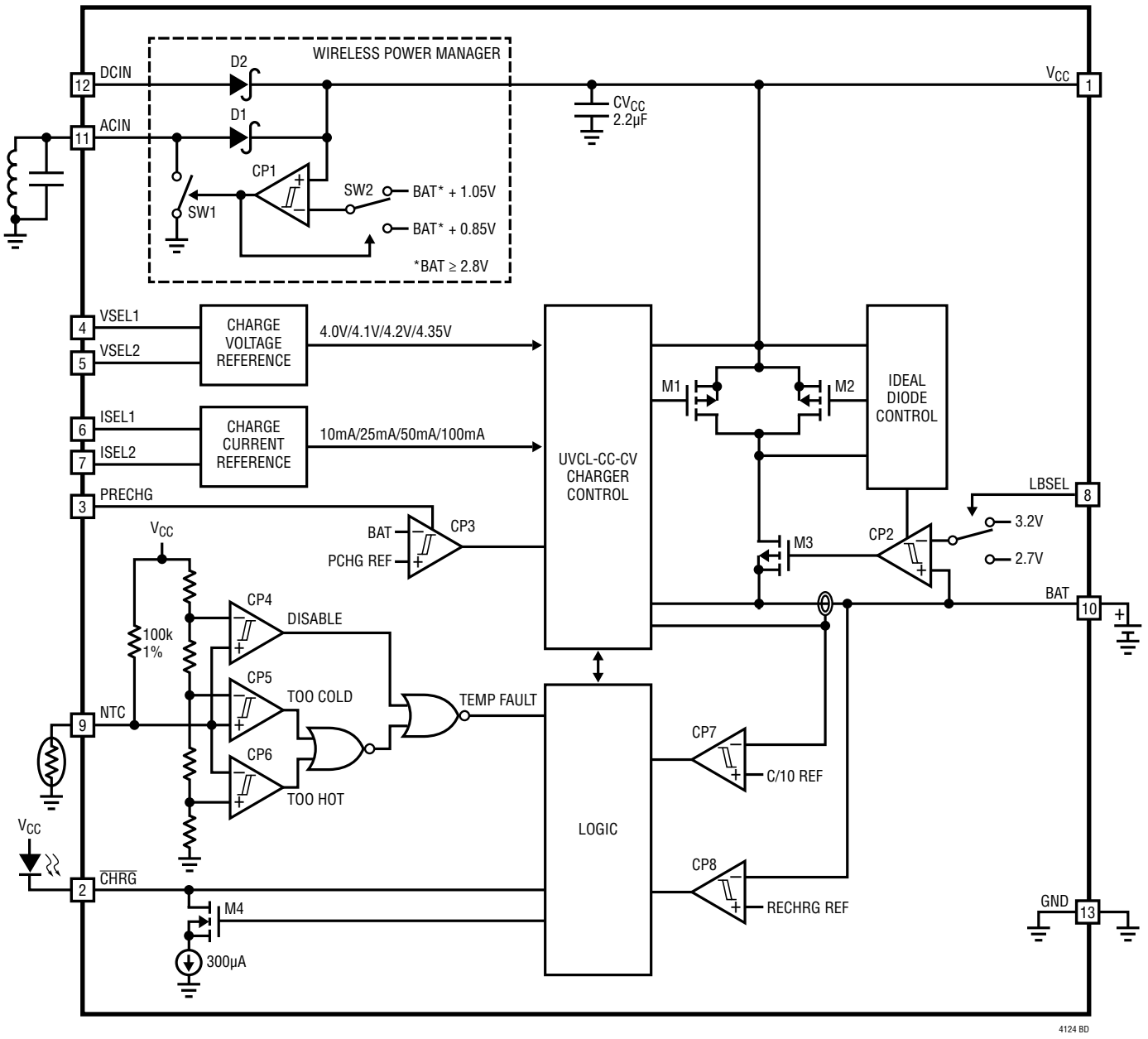
BAT (Pin 10): Battery. Connect the Li-Ion battery to this pin.

ACIN (Pin 11): AC Input Supply Voltage. Connect the external LC tank (receive inductor and capacitor) to this pin. An internal diode is connected from this pin (anode) to the V_{CC} pin (cathode). This pin supplies power to the V_{CC} pin when its peak voltage is higher than the DCIN pin voltage. Short this pin to GND when not used.

DCIN (Pin 12): Optional DC Input Supply Voltage: 3.3V to 5.5V. An internal diode is connected from this pin (anode) to the V_{CC} pin (cathode). This pin supplies power to the V_{CC} pin when its voltage is higher than the peak voltage of the ACIN pin. Short this pin to GND when not used.

GND (Exposed Pad, Pin 13): Device Ground. Connect this ground pin to a suitable PCB copper ground plane for proper electrical operation and rated thermal performance.

FUNCTIONAL BLOCK DIAGRAM



OPERATION

The LTC4124 is a wireless single cell Li-Ion battery charger. The part has three main components: a wireless power manager, a full-featured linear battery charger and an ideal diode PowerPath™ controller.

WIRELESS POWER MANAGER

A complete wireless power transfer system consists of transmit circuitry with a transmit coil and receive circuitry with a receive coil (Figure 1). The LTC4124 connected to an LC tank creates a simple and complete receiver half of the wireless power transfer system.

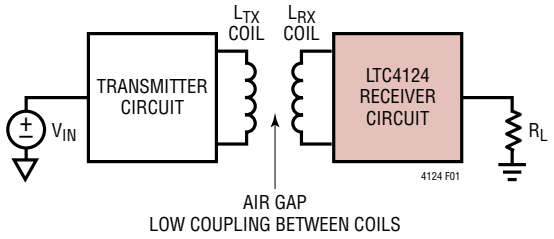


Figure 1. Wireless Power Transfer System

Refer to the Functional Block Diagram for the following discussion. An external parallel resonant LC tank connected to the ACIN pin allows the LTC4124 to receive power wirelessly from an alternating magnetic field generated by a transmit coil. Diode D1 rectifies the AC voltage at the ACIN pin. Comparator CP1, switch SW1 and switch SW2 operate together to regulate the rectified voltage on the V_{CC} pin to between 0.85V and 1.05V above the voltage on the BAT pin provided BAT ≥ 2.8V.

Operation with an Optional DC Voltage Source

The LTC4124 can alternately be powered from a DC voltage source connected to the DCIN pin. Diodes D1 and D2 set V_{CC} to the maximum of the voltage on the DCIN pin or the peak AC voltage on the ACIN pin. Therefore, the DCIN pin supplies power to the V_{CC} pin only if its voltage is higher than instantaneous AC voltage on the ACIN pin.

BATTERY CHARGER

The LTC4124 includes a pin programmable full-featured CC/CV (Constant Current/Constant Voltage) linear battery charger with safety timer termination, bad battery detection, temperature qualified safe charging and automatic recharge. The charge voltage and charge current are pin-strap programmable according to Table 2 and Table 3 shown in the Pin Functions section.

Figure 2 and Figure 3 show a typical charging cycle. As soon as the voltage at the V_{CC} pin reaches 3.4V, the charger attempts to charge the battery and a charge cycle is initiated. At the beginning of a charge cycle, when the battery voltage is typically less than the recharge threshold (97.6% of the final charge voltage), the charger is in CC mode and charges the battery at the full programmed current.

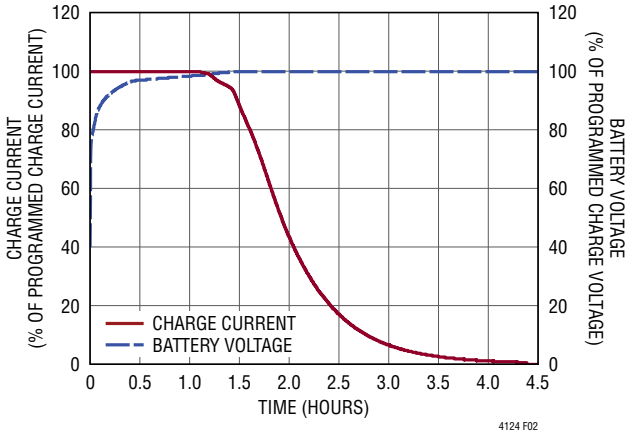


Figure 2. Typical Charging Cycle at 0.5C Rate vs Time with Pre-Charge Disabled

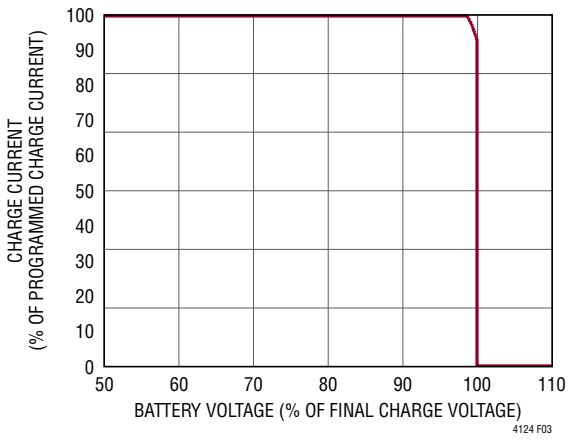


Figure 3. Typical Charge Current vs Battery Voltage in a Charging Cycle with Pre-Charge Disabled

OPERATION

When the voltage on the BAT pin approaches the final charge voltage, the charger enters CV mode. The charge current begins to drop and a 3-hour charge termination timer starts. The charge current continues to drop while the BAT pin voltage is maintained at the proper charge voltage. Both CC and CV charging are indicated by a slow blink (0.8Hz) at the $\overline{CHRG}$ pin.

In CV mode, when the charging current drops to 10% of the full programmed charge current, the $\overline{CHRG}$ pin stops blinking and assumes a pull-down state, but charging continues at a continuously decreasing low charge current level. After the 3-hour charge termination time expires, charging stops completely. To start a new charge cycle, remove the power source at ACIN or DCIN and reapply it.

Automatic Recharge

After charging has terminated and while still on the charger, the LTC4124 draws only 3.5µA from the battery. If it remains in this state for a long time (days for a typical battery with capacity ≥ 10mAh), the battery voltage will eventually drop enough due to this 3.5µA current and due to its own self-discharge to fall below the recharge threshold (V_{BAT_RECHG}).

To ensure that the battery is always topped off, a new charge cycle automatically begins when the battery voltage falls below V_{BAT_RECHG} (typically 97.6% of the programmed charge voltage). In the event that the 3-hour safety timer is still running when the battery voltage falls below V_{BAT_RECHG}, the timer resets back to zero.

Trickle Charging – PRECHG Pin

Some battery manufacturers recommend low current pre-charging (trickle charge) for batteries that have been deeply discharged. Tying the PRECHG pin to V_{CC} enables the LTC4124 trickle charge feature.

When enabled, the trickle charge feature reduces the delivered charge current in CC mode to 10% of the full programmed charge current if the battery voltage is below the pre-charge battery voltage threshold (V_{BAT_TRKL} is 68% of programmed charge voltage). Figure 4 and Figure 5 show a typical charging cycle with pre-charge enabled.

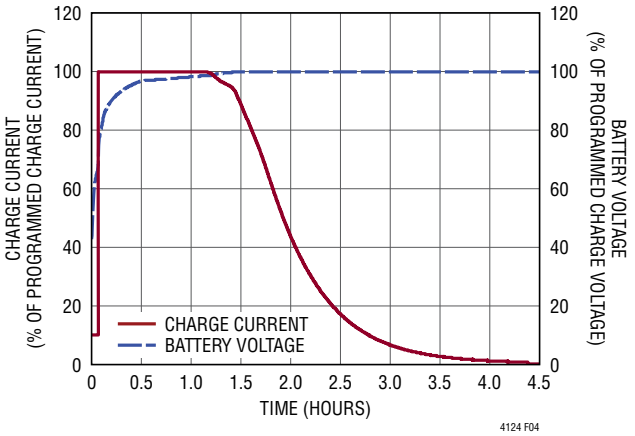


Figure 4. Typical Charging Cycle at 0.5C Rate vs Time with Pre-Charge Enabled

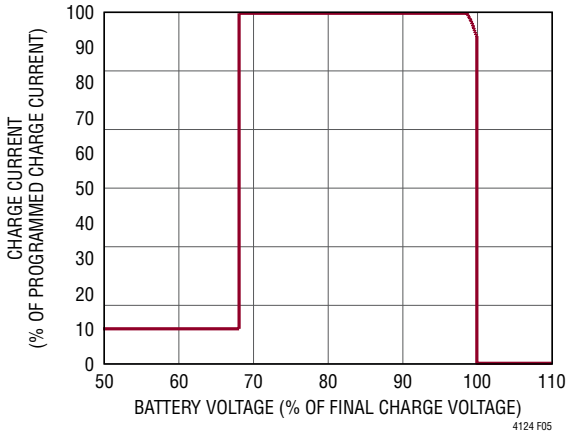


Figure 5. Typical Charge Current vs Battery Voltage in a Charging Cycle with Pre-Charge Enabled

Note that tying the PRECHG pin to GND disables the LTC4124 trickle charge feature. When disabled, full charge current is delivered to the battery in CC mode, resulting in the typical charge cycle as shown in Figure 2 and Figure 3.

Bad Battery Fault

If during any charging cycle, the battery voltage stays below the pre-charge V_{BAT_TRKL} for longer than the bad battery detection time (t_{BB}), the battery is deemed faulty and the $\overline{CHRG}$ pin indicates this bad battery fault condition by blinking fast (6Hz).

OPERATION

UVCL

The LTC4124 charger also includes undervoltage current limiting (UVCL) which gradually reduces the charge current from the full programmed value towards zero as the V_{CC} voltage drops to 3.4V. When the V_{CC} voltage is less than 3.45V, the $\overline{CHRG}$ pin blinks fast (6Hz) to indicate a UVCL fault.

This feature is particularly useful in situations where the wireless power available is limited. Without UVCL, if the magnetic coupling between the receive coil and the transmit coil is low, the V_{CC} voltage could be forced below the acceptable minimum operating voltage (2.7V) when the charger tried to provide the full charge current. When this V_{CC} minimum operating voltage is not met, the LTC4124 forces the charge current to drop to zero instantly, allowing the V_{CC} voltage to rise above this minimum operating voltage and thus turn on the charger again.

This oscillatory behavior would result in intermittent charging. The UVCL feature prevents this undesirable behavior by gradually increasing or decreasing the charge current as input power becomes more or less available.

Temperature Qualified Charging – NTC

The LTC4124 also includes an NTC pin, which provides for temperature qualified charging when connected to a 100kΩ NTC (negative temperature coefficient) thermistor thermally coupled to the battery. Comparators CP5 and CP6 implement the temperature detection as shown in the Functional Block Diagram.

The rising threshold of CP5 is set at 75% of V_{CC} (cold threshold) and the falling threshold of CP6 is set at 35% of V_{CC} (hot threshold). When the voltage at the NTC pin is above 75% of V_{CC} or below 35% of V_{CC}, the LTC4124 pauses any charge cycle in progress. When the voltage at the NTC pin returns within the range of 40% to 70% of V_{CC}, charging resumes.

When charging is paused, the charge current drops to zero. If the LTC4124 is charging in constant voltage mode and the charge termination timer is running, the timer pauses until the thermistor indicates a return to a valid temperature. Similarly, if the battery charger is in trickle charge mode and the bad battery detection timer is running, the bad battery timer pauses until the thermistor indicates a return to a valid temperature.

To disable the temperature qualified charging feature of the LTC4124, the NTC pin can be left open or shorted to the V_{CC} pin. In this configuration, comparator CP4 ensures that the output of the temperature detection comparators CP5 and CP6 are ignored and no temperature fault will be detected.

Charge Status Indicator

The status of the battery charger is indicated via the open drain $\overline{CHRG}$ pin. This pin has an internal 300µA pull-down current. An LED can be connected between this pin and V_{CC} to indicate the charging status and any fault condition as indicated in Table 1 shown in the Pin Functions section.

Low Battery Disconnect

When no input power is available and the battery voltage falls below the disconnect voltage (V_{BAT_LBDIS}), the LTC4124 shuts down, opening disconnect switch M3 (Functional Block Diagram) and eliminating any current consumption from the battery. This protects the battery from discharging further and causing damage that will reduce battery lifetime. When the battery is in disconnect mode, normal functioning can only resume by applying power to the ACIN or DCIN pin.

The disconnect voltage level can be selected via the LBSEL pin according to Table 4 shown in the Pin Functions section.

Ship Mode

The LTC4124 also provides a ship mode feature. When activated, this feature eliminates any current consumption from the battery at any battery voltage level. This feature ensures that all battery powered devices using the LTC4124 can be shipped out of the factory with a charged battery (conditioned for optimal storage life or fully charged) with the expectation that it is ready to be used (minimal discharge) the first time it reaches the end user.

OPERATION

Ship mode activates when a 1.5V (± 100mV) DC voltage is simultaneously applied to both the DCIN and the ACIN pins while the LTC4124 is in ideal diode mode (the battery is supporting the V_{CC} voltage at or above the battery disconnect voltage V_{BAT_LBDIS}).

Before entering ship mode, the voltage at V_{CC} will be at V_{BAT} – 50mV. As soon as 1.5V is simultaneously applied to the DCIN and ACIN pins, the voltage at V_{CC} will drop to a diode drop below 1.5V (approximately 0.7V), indicating that the part is now in ship mode. Finally, set the DCIN and ACIN pins to 0V to let the V_{CC} pin voltage drop to 0V.

In a typical setup, an R_X coil is connected between the ACIN pin and GND. Thus, driving the ACIN pin with a 1.5V DC voltage is not prudent without temporarily removing this coil connection. An alternate and more practical procedure for entering ship mode is as follows:

1. With DCIN = 0V, ensure that the LTC4124 is in ideal diode mode (the battery is supporting the V_{CC} voltage at or above the battery disconnect voltage V_{BAT_LBDIS}).
2. Turn on the transmitter and couple the T_X coil to the R_X coil so that the LTC4124 is in charging mode (V_{CC} is supported by ACIN at or above the battery voltage).
3. Drive the DCIN pin to 1.5V DC.
4. Turn off the transmitter.
5. Ensure that the V_{CC} voltage drops to a diode drop below 1.5V (approximately 0.7V).
6. Remove the 1.5V DC source from the DCIN pin and drive it to 0V.
7. Ensure that the V_{CC} voltage goes to 0V.

Once in ship mode, normal functioning of the LTC4124 can only resume again by applying power to the ACIN or DCIN pin to bring the voltage at V_{CC} above the 2.7V minimum operating voltage.

IDEAL DIODE POWER PATH FROM BAT TO V_{CC}

When the LTC4124 is not in low battery disconnect mode nor in ship mode, the Ideal Diode Control block (Functional Block Diagram) regulates V_{CC} to achieve low loss conduction by driving the gate of M2 such that the voltage drop from the BAT pin to the V_{CC} pin is 50mV. At high load currents from V_{CC}, M2 is fully driven on with its on-resistance adding to that of M3 connecting BAT to V_{CC}.

The Charger Control block driving M1 together with the Ideal Diode Control block driving M2 allow for a smooth transition from charging mode to the low loss discharge mode. Note that in charging mode, current is flowing from the V_{CC} pin to the BAT pin. In the low loss discharge (ideal diode) mode, current is flowing from the BAT pin to support the V_{CC} pin voltage to be as close to that of the BAT pin as possible.

APPLICATIONS INFORMATION

The LTC4124 is designed to be a highly integrated complete solution for a wireless single cell Li-Ion battery charger. As such its application circuit is simple with a minimal number of external components.

COMPONENT SELECTION

In the simplest application with a DC input voltage and no wireless power input, a single cell Li-Ion battery charger with the LTC4124 requires no external components at all (Figure 6). Note that even though this simplest application is a complete functional single cell Li-Ion battery charger, it does not have the temperature qualified charging feature nor does it have any visual charge status indicator.

In order to include the temperature qualified charging, a negative temperature coefficient (NTC) thermistor needs to be added. To add a visual charge status indicator, an LED needs to be connected between the V_{CC} pin and the $\overline{CHRG}$ pin. Figure 7 shows these two components added to the application circuit of Figure 6.

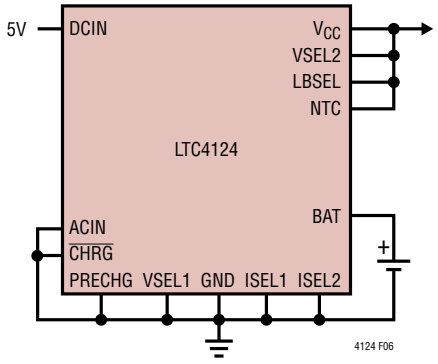


Figure 6. Simplest 10mA Single Cell Li-Ion Charger with LTC4124 with No Temperature Qualified Charging and No Charge Status Indicator

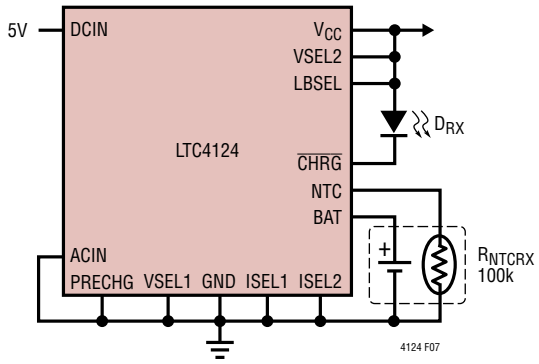


Figure 7. Simple 10mA Single Cell Li-Ion Charger with DC Input

NTC Thermistor

To use the battery temperature qualified charging feature, connect a 100kΩ NTC thermistor between the NTC pin and GND. Thermistor manufacturer data sheets usually include either a temperature lookup table or a formula relating temperature to the resistance at that corresponding temperature. Table 5 shows some thermistors that can be used with the LTC4124.

Table 5. Recommended NTC Thermistors

Manufacturer	Part Number	Description
TDK	NTCG064EF104F	100kΩ, 1%, 0201
MURATA	NCP03WF104F	100kΩ, 1%, 0201

In the setup shown in Figure 7, the LTC4124 will pause charging at higher temperatures when the resistance of the NTC thermistor drops to 54kΩ. For the thermistors listed in Table 5, this corresponds to approximately 43°C. As temperature drops, the resistance of the NTC thermistor rises. The LTC4124 will also pause charging when the value of the NTC thermistor increases to 300kΩ. For the thermistors listed in Table 5, this corresponds to approximately 3°C. For the same thermistors in Table 5, the hot and cold comparators each have approximately 5°C of hysteresis to prevent oscillation about the trip point.

APPLICATIONS INFORMATION

LED

The LED connected to the $\overline{CHRG}$ pin is powered by a 300µA pull-down current source. Select a high efficiency LED with a low forward voltage drop. Some recommended LEDs are shown in Table 6.

Table 6. Recommended LEDs

Manufacturer	Part Number	Description
Kingbright	APG0603VGC	Green, 0201
Kingbright	APG0603SEC-E-TT	Red, 0201

Wireless Power Components

In order for the LTC4124 to receive power wirelessly, a parallel LC tank needs to be connected to the ACIN pin as shown in the Functional Block Diagram. The inductor L acts as the receive coil, and together with the capacitance C, creates a resonant tank circuit. Power transmission across the weakly coupled link between the transmit coil and the receive coil (Figure 1) can be greatly improved when this tank circuit is tuned to the same frequency as the transmit coil AC current frequency.

Receive Coil/Resonant Inductor L

The most important factor in selecting the receive coil is the quality factor of the coil:

$$Q_L = \frac{\omega_n L}{R_S}$$

where ω_n is the operating resonant frequency in rad/s and R_S is the parasitic series resistance of the coil. Often this quality factor is limited by the size of the application. The smaller the size of the application, the harder it is to fit wire with small series resistance to generate higher inductance values. Therefore, in many cases, users are recommended to first consider the overall size of their end application and then decide on the biggest possible coil that fits this end application device.

Another commonly employed method to improve the Q value of the receive coil is the use of a ferrite core on the coil. Figure 8 shows a commonly employed ferrite core in the form of a sheet at both the T_X and R_X coils.

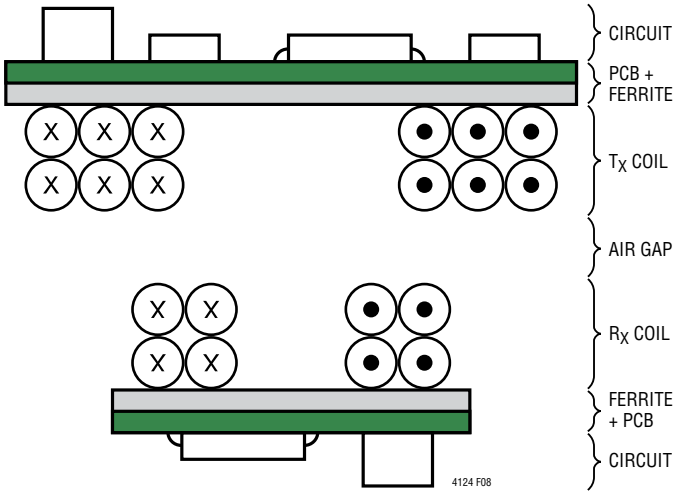


Figure 8. Cross Section of T_X and R_X Coils with Ferrite Sheets

The presence of this ferrite core increases the self-inductance value of each coil, which increases the Q. More importantly, proper placement of this ferrite material helps shape the magnetic field between the T_X and R_X coils which greatly improves the coupling or the mutual inductance between these two coils. Stronger coupling translates to better power transfer and higher efficiency.

Additionally this ferrite core helps shield the rest of the transmit and receive circuits which may be placed on the opposite side of the magnetic link (air gap in Figure 8). Table 7 lists some recommended inductors of different sizes for applications with the LTC4124.

Table 7. Recommended Receive Coils

Manufacturer	Part Number	Description
Wurth Elektronik	760308101216	7.2µH, 6mm ø
Wurth Elektronik	760308101208	13µH, 10mm ø
Wurth Elektronik	760308101220	12.6µH, 17mm ø

APPLICATIONS INFORMATION

Resonant Frequency Selection

As noted in the quality factor discussion of the receive coil, the higher the frequency of operation, the higher the quality factor of the coil. However, there are several limitations to setting the operating frequency to an arbitrarily high value.

The first is the self-resonant frequency of the coil. For the coils listed in Table 7, their self-resonant frequencies vary from 19MHz to 32MHz. The operating frequency should be set at least a factor of 5 below the coil self-resonant frequency so that this operating frequency can be well controlled by selecting the appropriate resonant capacitor value.

The second limitation is the transmitter circuit driver capability and efficiency. In most wireless power applications, the transmit circuit includes a DC to AC converter. The higher the operating frequency, the faster some elements of the transmit circuit need to switch. The speed at which these elements can be switched is often limited due to the architecture or process technology. Furthermore, a higher switching frequency lends itself to higher switching losses, which in turn reduces overall efficiency.

Therefore, as a guideline, the user should select a high operating frequency that is appropriate for the selected coils and transmitter circuit driver. The main trade-off is between the loss in efficiency of the transmitter circuit driver operating at higher frequency and the increase in coil to coil power transfer due to the higher Q of the coils. The LTC4124 is appropriate for systems with resonant frequencies anywhere from 50kHz up to 10MHz.

Resonant Capacitor C

Once the coil and the operating frequency are selected, the value of the resonant capacitor is determined by the following formula:

$$C = \frac{1}{\omega_n^2 L}$$

where ω_n is the operating resonant frequency in rad/s and L is the receive coil inductance. Select capacitors with low ESR and low thermal coefficients such as COG or X7R ceramic. In general, the higher the voltage rating of the capacitor, the lower the dissipation factor of its dielectric material but also the larger the size would be. The dissipation factor of a capacitor includes the ESR as one of its main components. Note that this dissipation factor is not usually listed in a standard capacitor data sheet.

Table 8 lists some recommended capacitors of different sizes for applications with the LTC4124.

Table 8. Recommended Resonant Capacitors

Manufacturer	Part Number	Description
Murata	GRM155R71H332JA01D	50V, 0402, 3.3nF
Murata	GRM155R71H683KE14J	50V, 0402, 68nF
Murata	GRM155R71H333KE14D	50V, 0402, 33nF
TDK	CGA4J2C0G1H333J125AA	50V, 0805, 33nF

Choosing Transmit Power Level

The transmit power level should be set as low as possible for the receiver to receive the desired output power under the worst-case coupling conditions (i.e. maximum transmit distance with the worst-case alignment). Although the LTC4124 is capable of shunting excess received power to maintain the V_{CC} voltage in the desired range, its temperature will rise when shunting excess power. Careful evaluation of the application needs to be performed to ensure that the operating temperature range of the LTC4124 and the end application is not exceeded.

Empirically, the determination of transmit power level of the application circuit can be done by first setting the transmit inductor current at the highest rated current possible based on the transmit coil specification. From this starting point, transmit power can then be adjusted lower until the charge current of the LTC4124 on the receive side is negatively impacted under worst-case coupling conditions. Once this minimum transmit power level is determined, the transmit and receive coils should be arranged under best-case coupling conditions with a fully charged battery to make sure that the shunting of excess power by the LTC4124 does not raise its temperature too much.

In addition to temperature, another parameter that needs to be checked is the maximum negative voltage on the

APPLICATIONS INFORMATION

ACIN pin. Following the procedure above, when evaluating the rise in temperature of the LTC4124 under the best-case coupling conditions, ensure that $V_{VCC} – V_{ACIN}$ does not exceed 40V. Figure 9 shows a typical waveform on ACIN showing $V_{CC} – V_{ACIN} < 40V$.

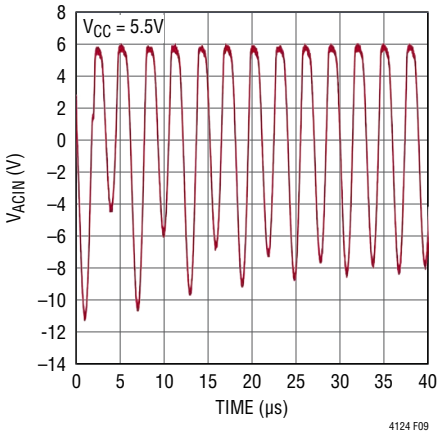


Figure 9. Typical Acceptable Voltage Waveform on the ACIN pin with $V_{CC} – V_{ACIN} < 40V$.

As an alternative to using the empirical method to determine the maximum negative voltage on the ACIN pin, the following formula can be used in conjunction with Figure 10, which shows a parallel resonant configuration on the receiver:

$$|V_{RX}| = \frac{\omega k \sqrt{L_{TX} L_{RX}}}{\sqrt{\left(1-\omega^2 L_{RX} C_{RX}\right)^2 + \left(\omega \frac{L_{RX}}{R_{L-AC}}\right)}} |I_{TX}|$$

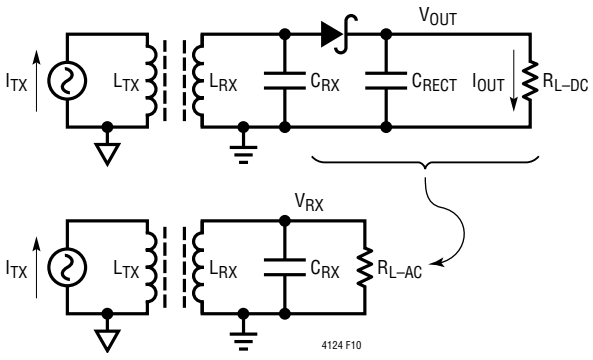


Figure 10. Modeling Parallel Resonant Configuration and Half Wave Rectifier on the Receiver

$|V_{RX}|$ is the amplitude of the voltage on the receiver coil, $|I_{TX}|$ is the amplitude of the current in the transmit coil, k is the coupling factor between the transmit and receive coils, ω is the operating frequency in radians per second, L_{TX} is the self-inductance of the transmit coil, L_{RX} is the self-inductance of the receive coil, C_{RX} is the receiver resonant capacitance, and R_{L-AC} is the equivalent AC load resistance.

One simplification is as follows:

$$R_{L-AC} \approx \frac{R_{L-DC}}{2}$$

which assumes that the drop across the Schottky diode is much smaller than the amplitude $|V_{RX}|$. Additionally, R_{L-DC} can be approximated as the ratio of the output voltage (V_{OUT}) to the output current (I_{OUT}):

$$R_{L-DC} = \frac{V_{OUT}}{I_{OUT}}$$

The amplitude of the current in the transmit coil $|I_{TX}|$ can be either measured directly or its initial (no receiver) value can be calculated based on the transmitter circuit as described in the applications example. This initial value is a conservative estimate since the amplitude of the transmitter coil current will drop as soon as the receiver, with a load, is coupled to it.

The coupling factor (k) between the two coils could be obtained by running a finite element simulation inputting the coil dimensions and physical configurations. An easier method to obtain this coupling number, is to use the series-aiding and series-cancelling empirical measurement method for two loosely coupled coils as shown in Figure 11.

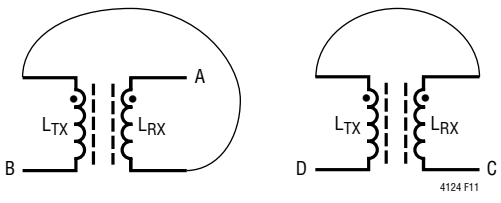


Figure 11. Series-Aiding and Series-Cancelling Method Configurations Used for Measuring the Coupling Factor k

APPLICATIONS INFORMATION

And:

$$L_{AIDING} = L_{AB}$$

$$L_{CANCELLING} = L_{CD}$$

$$k = \frac{L_{AIDING} - L_{CANCELLING}}{4\sqrt{L_{TX}L_{RX}}}$$

PC BOARD LAYOUT CONSIDERATIONS

Since the exposed pad of the LTC4124 package is the only ground connection and serves as the return path for both the charger and the DC/DC converter, it must be soldered to the PC board ground for a good electrical connection. The shunt circuitry in the Wireless Power Manager block (Functional Block Diagram) dissipates some power within the IC that may cause the die temperature to rise. For optimum thermal performance, there should be a group of vias directly under the exposed pad on the backside leading directly down to a ground plane on layer 2.

Figure 12 shows a recommended layout of a complete LTC4124 application PC Board. The diameter of this general purpose board, which allows for all permutations for the pin programmable settings, is only 5.2mm.

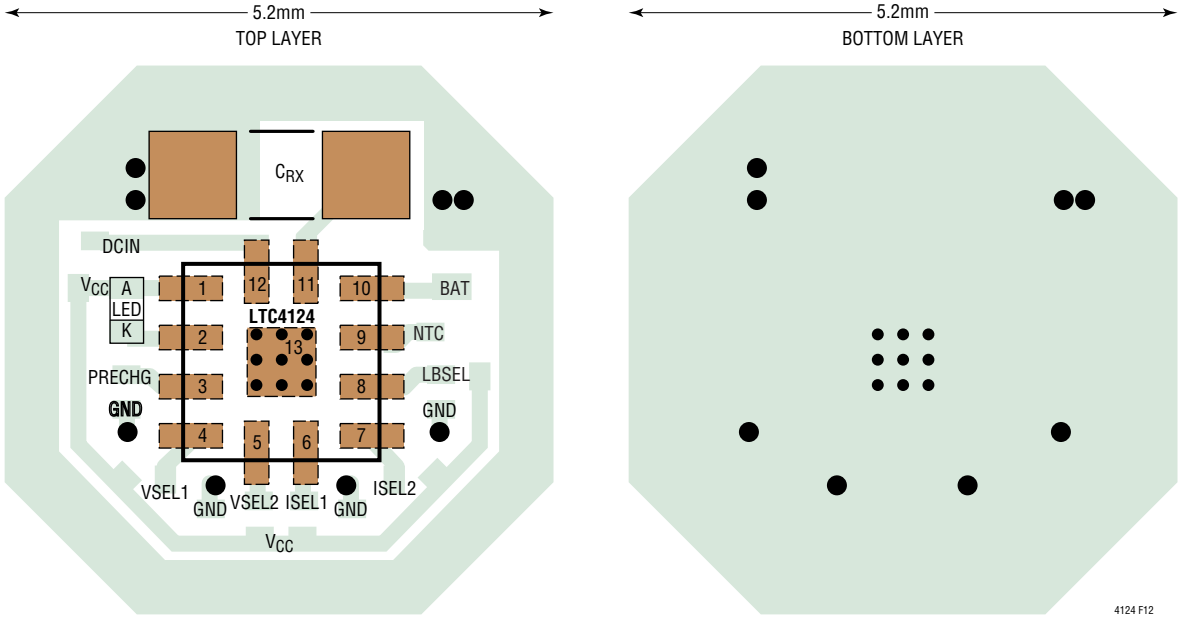


Figure 12. Recommended Minimum Footprint Layout

APPLICATIONS INFORMATION

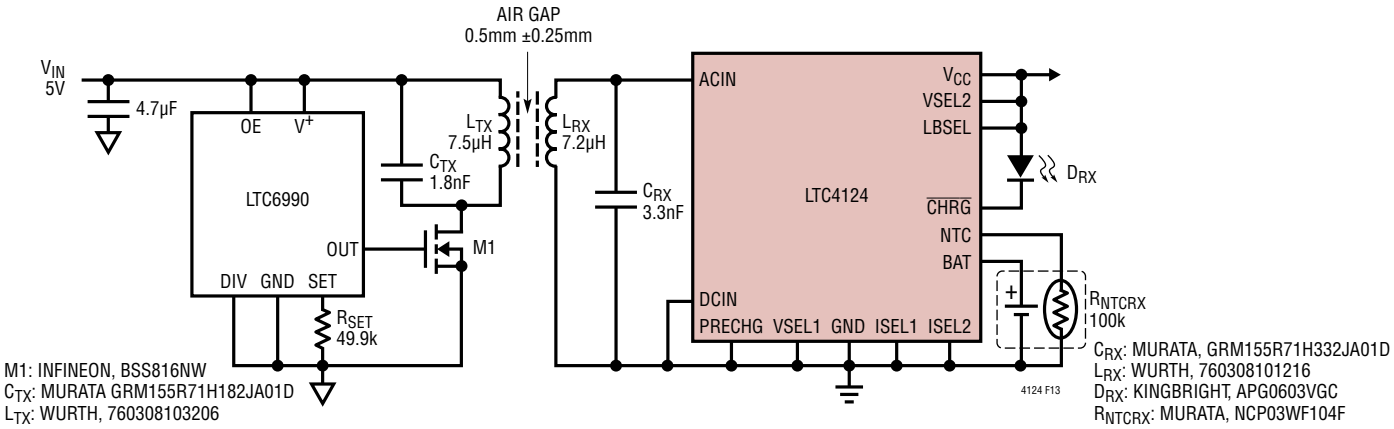


Figure 13. Single Transistor Transmitter and LTC4124 10mA Charger Receiver

DESIGN EXAMPLE 1: SINGLE TRANSISTOR TRANSMITTER AND LTC4124 10mA CHARGER RECEIVER

The single transistor transmitter shown in Figure 13 is an example of a DC/AC converter that can be used to drive AC current into a transmit coil, L_{TX}. NMOS switch M1 is driven by a 50% duty cycle square wave generated by the LTC6990 oscillator. During the first half of the cycle, M1 is on and the current through L_{TX} rises linearly. During the second half of the cycle, M1 is off and the current through L_{TX} circulates through the LC tank formed by C_{TX} and L_{TX}. The current through L_{TX} is shown in Figure 14.

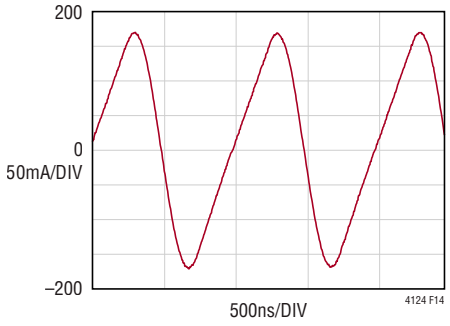


Figure 14. Current Through Transmit Coil

If the transmit LC tank frequency is set to 1.29 times the driving frequency, switching losses in M1 are significantly reduced due to zero voltage switching (ZVS). Figure 15 and Figure 16 illustrate the contrast in the switching waveforms when the tank frequency is set at different values.

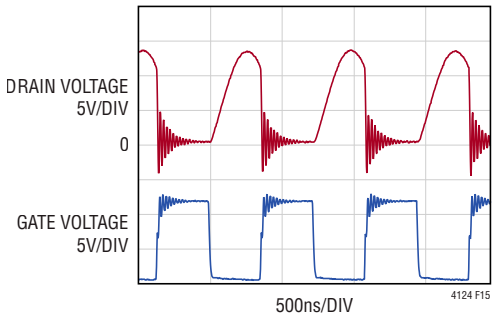


Figure 15. Voltage on the Drain and Gate of NMOS M1 when $f_{TX\text{-}TANK} = f_{DRIVE}$

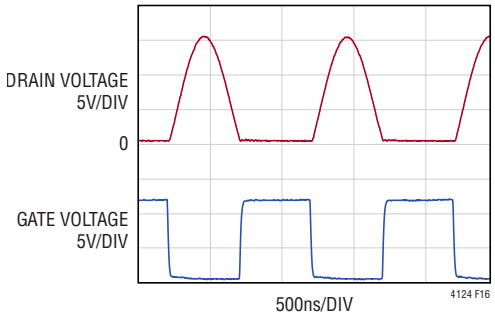


Figure 16. Voltage on the Drain and Gate of NMOS M1 when $f_{TX\text{-}TANK} = 1.29 \bullet f_{DRIVE}$

APPLICATIONS INFORMATION

Therefore, the ZVS condition is achieved when the following condition is satisfied:

$$f_{TX\text{-}TANK} = 1.29 \bullet f_{DRIVE}$$

where f_{DRIVE} is set by resistor R_{SET} connected to the LTC6990. $f_{TX\text{-}TANK}$ is set by:

$$f_{TX-TANK} = \frac{1}{2\pi\sqrt{L_{TX} \bullet C_{TX}}}$$

The peak voltage of the transmit coil, L_{TX}, that appears at the drain of M1 is:

$$V_{TX\text{-}PEAK} = 1.038 \bullet \pi \bullet V_{IN}$$

And the peak current through L_{TX} is:

$$I_{TX-PEAK} = \frac{0.36 \bullet V_{IN}}{f_{TX-TANK} \bullet L_{TX}}$$

The RMS current through L_{TX} is:

$$I_{TX\text{-}RMS} = 0.66 \bullet I_{TX\text{-}PEAK}$$

The LC tank at the receiver, L_{RX} and C_{RX}, is tuned to the same frequency as the driving frequency of the transmit LC tank:

$$f_{RX\text{-}TANK} = f_{DRIVE}$$

where $f_{RX\text{-}TANK}$ is given by:

$$f_{RX-TANK} = \frac{1}{2\pi\sqrt{L_{RX} \bullet C_{RX}}}$$

Note that since f_{DRIVE} can be easily adjusted by changing the value of R_{SET}, it is best practice to choose $f_{RX\text{-}TANK}$ using the minimum component count (i.e. standard value for C_{RX}) and then adjusting f_{DRIVE} to match. The receiver resonant frequency can be selected using the guideline described in the resonant frequency selection section.

The amount of AC current in the transmit coil can be increased by increasing the supply voltage (V_{IN}). Since the amount of power transmitted is proportional to the AC current in the transmit coil, V_{IN} can be varied to adjust the power delivery to the receive coil. When adjusting the supply voltage, care needs to be taken that the absolute maximum voltage rating of the LTC6990 pins as well as the maximum drain to source voltage rating of NMOS M1 are not exceeded.

The steps needed to determine each of the component values for the circuit shown in Figure 13 are reviewed here:

1. Determine the receiver resonant frequency and set component values for the receiver LC tank:

   As discussed in previous sections, the resonant frequency should be selected such that it is at least a factor of 5 below the self-resonant frequency of the coils and within the capability of the transmitter driver circuit. In this example, the self-resonant frequency of the R_X coil is 32MHz and the T_X coil is 23MHz. So a factor of 5 below 23MHz is 4.6MHz.

   The transmitter driver circuit in this example is the LTC6990 driving an N-Channel MOSFET from Infineon (BSS816NW). This particular MOSFET has a total gate charge (Q_g) of 600pC. The output driver resistance of the LTC6990 is 150Ω. Therefore, the expected time constant of the waveform on the gate of the MOSFET is 90ns. In order for the rise and fall times of the waveform not to take more than 20% of the total waveform period, the maximum switching frequency of this waveform should be about 1MHz.

   It is best practice to select a resonant frequency that yields a low component count on the receiver to ensure the smallest footprint in an often space-constrained receiver device.

   In this example, 1MHz is selected as the receiver resonant frequency. At 1MHz, the tank capacitance (C_{RX}) required with the selected receive coil (7.2µH) is 3.3nF. Since 3.3nF is a standard value for capacitors, the tank capacitance requires only one component. The tank capacitance calculation is shown below.

   $$C_{RX} = \frac{1}{4 \bullet \pi^2 \bullet f_{RX-TANK}^2 \bullet L_{RX}} = 3.5nF \approx 3.3nF$$

   Following the guidance on selecting the resonant capacitor, select a 3.3nF capacitor with the highest voltage rating while keeping the footprint to an acceptable size. In this particular example, a 3.3nF capacitor with a 25V voltage rating and a small 0603 footprint is chosen.

APPLICATIONS INFORMATION

2. Set the driving frequency (f_{DRIVE}) for the single transistor transmitter:

   f_{DRIVE} is set to the same value as the receiver resonant frequency:

   $$R_{SET} = \frac{1MHz}{f_{OUT}} \bullet \frac{50k\Omega}{N_{DIV}} = \frac{1MHz}{1MHz} \bullet \frac{50k\Omega}{1} = 50k\Omega$$

   where N_{DIV} = 1 as the DIV pin of the LTC6990 is grounded. Select a 49.9kΩ (standard value) resistor with 1% tolerance. For more information regarding the oscillator, consult the LTC6990 data sheet.

3. Set the LC tank component values for the single transistor transmitter: If f_{DRIVE} is 1MHz, the transmit LC tank frequency ($f_{TX-TANK}$) is:

   $$f_{TX-TANK} = 1.29 \bullet 1MHz = 1.29MHz$$

   The transmit coil (L_{TX}) used in this example is 7.5µH. The value of transmit tank capacitance (C_{TX}) can be calculated:

   $$C_{TX} = \frac{1}{4 \bullet \pi^2 \bullet f_{TX-TANK}^2 \bullet L_{TX}} = 2.0nF$$

   Accounting for the parasitic capacitance on the drain of M1, a C_{TX} value of 1.8nF is chosen. The recommended rating for C_{TX} capacitors is 50V with 5% (or better) tolerance.

4. Verify that the AC current through the transmit coil is well within its rating. In this example, the supply voltage to the single transistor transmitter is 5V. The peak AC current through the transmit (L_{TX}) coil can be calculated as:

   $$I_{TX-PEAK} = \frac{0.36 \bullet V_{IN}}{f_{TX-TANK} \bullet L_{TX}} = \frac{0.36 \bullet 5V}{1.29 \times 10^6 \bullet 7.5\mu H}$$

   $$I_{TX-PEAK} = 0.19A$$

   and the RMS current as:

   $$I_{TX-RMS} = 0.66 \bullet 0.19A = 0.13A$$

   The I_{TX-RMS} is well below the 1.55A max rated current for the transmit coil (see the Wurth Elektronik 760308103206 data sheet for more information).

5. Also verify that the transmit power level chosen does not result in excessive heating nor excessive negative voltage on the ACIN pin of the LTC4124.

   Using the guidelines described in the Choosing Transmit Power Level section, the transmit and receive coils should be arranged under best-case coupling conditions with a fully charged battery, and the steady state temperature of the LTC4124 should then be measured. Additionally, $V_{VCC} – V_{ACIN}$ should also be verified.

   The best coupling condition typically occurs with the smallest air gap between the coils and the two coils in a concentric arrangement. However in this particular example, the transmit coil shape is elliptical. Figure 17 shows the 2D physical arrangement resulting in best-coupling conditions for the two coils in this example.

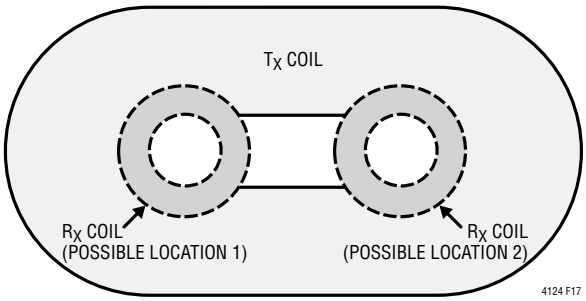


Figure 17. Best Coupling Condition for the Coils in Design Example 1

If we set the air gap to 0mm minimum, the maximum temperature rise of the LTC4124 is 12°C and the maximum $V_{VCC} – V_{ACIN}$ is 13V.

This result is verified using the alternative formula provided in the Choosing Transmit Power Level section. Using the suggested method, the coupling value at the best coupling condition is 0.04. Using this coupling value, the predicted value of the minimum negative voltage developed on the ACIN is –8V. Therefore, the predicted maximum $V_{VCC} – V_{ACIN}$ is 13V as verified empirically.

APPLICATIONS INFORMATION

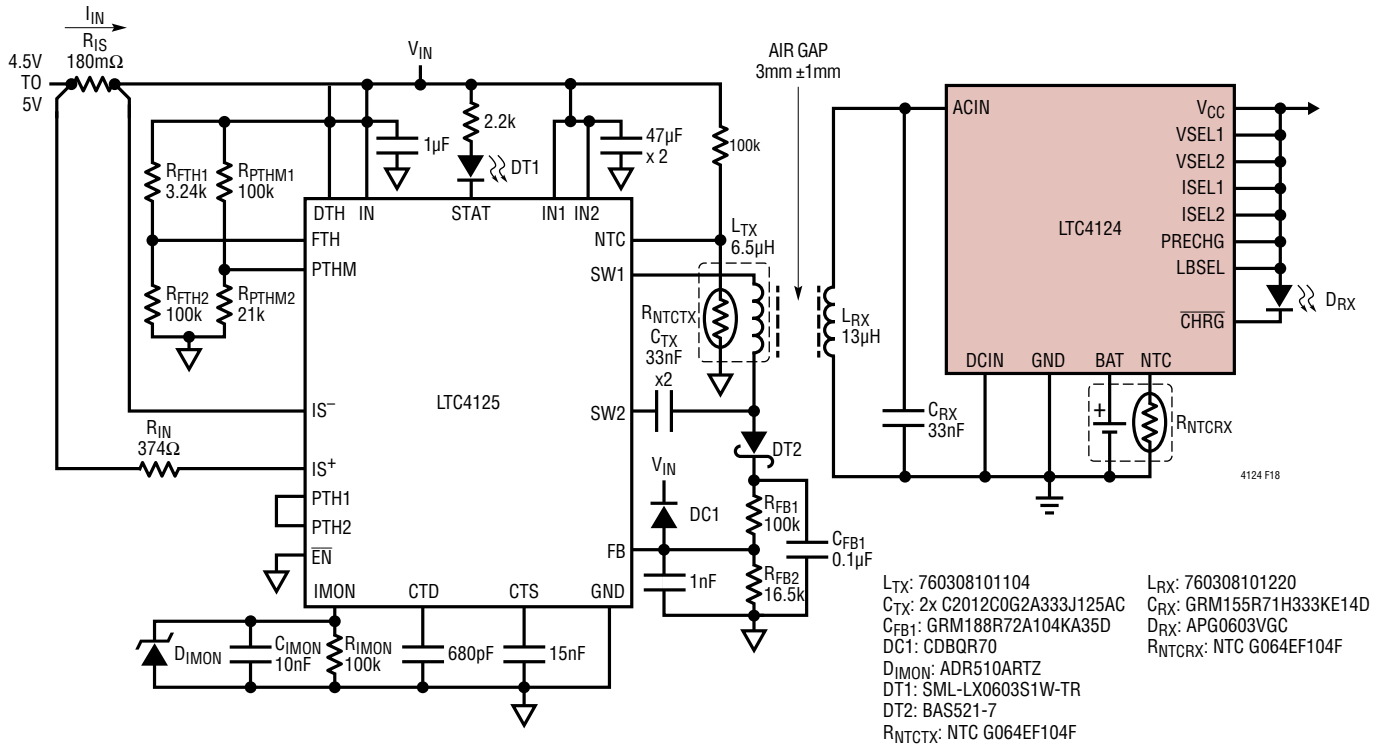


Figure 18. LTC4124 100mA Charger Receiver with LTC4125 AutoResonant Transmitter

DESIGN EXAMPLE 2: LTC4124 100mA CHARGER RECEIVER WITH LTC4125 AutoResonant® TRANSMITTER

Figure 18 shows a complete schematic of a wireless battery charger application showcasing the LTC4124 charging at 100mA. The transmitter circuit uses the LTC4125 AutoResonant Wireless Power Transmitter IC.

The LTC4125 drives a series LC network connected to its switch pins at its resonant frequency. The LTC4125 auto resonant drive ensures that the voltage across its SW1 and SW2 pins is always in phase with the current in the transmitter series LC network as shown in Figure 19.

The LTC4125 also pulse width modulates the voltage across its SW1 and SW2 pins in order to control the amount of transmit coil current. Figure 20 shows the transmitter LC tank current and voltage waveforms when the drive pulse width results in a duty cycle less than 50%.

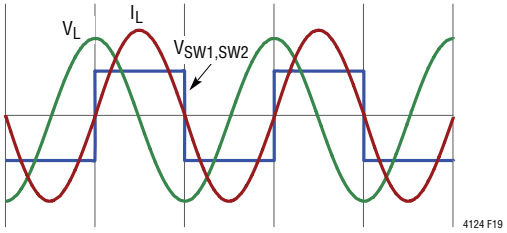


Figure 19. Transmitter Series LC Tank Voltage and Current Waveforms with $V_{SW1,SW2}$ at 50% Duty Cycle

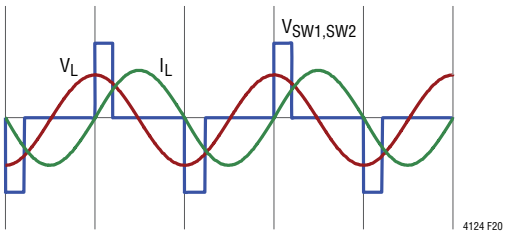


Figure 20. Transmitter Series LC Tank Voltage and Current Waveforms with $V_{SW1,SW2}$ at Less Than 50% Duty Cycle

APPLICATIONS INFORMATION

The LTC4125 also features the ability to sense the load at the receiver which allows it to go to a low power operating state in the absence of a receiver. Furthermore, it has a foreign object detection feature which prevents inadvertent wireless transmission of power to a conductive foreign object. Refer to the LTC4125 data sheet for more details on the LTC4125 operation and applications.

The steps needed to determine each of the component values for the circuit shown in Figure 18 are reviewed here:

1. Determine the receiver resonant frequency and set component values for the receiver LC tank:

   Similar to the first design example, the resonant frequency should be selected such that it is at least a factor of 5 below the self-resonant frequency of the coils and within the capability of the transmitter driver circuit. In this example, the self-resonant frequency of the R_X coil is 19MHz and of the T_X coil is 20MHz. So a factor 5 below 19MHz is 3.8MHz.

   The LTC4125 transmitter IC has a maximum switching frequency of 320kHz. It is best practice to select a resonant frequency that yields a low component count on the receiver to ensure the smallest footprint.

   In this example, 240kHz is selected as the receiver resonant frequency. At 240kHz, the tank capacitance (C_{RX}) required with the selected receive coil (13µH) is 33nF.

   Following the guidance on selecting the resonant capacitor, in this particular example a 33nF capacitor with a 50V voltage rating and a small 0402 footprint is chosen.

2. Set the transmitter LC tank component values to match the receiver resonant frequency.

   The transmit LC tank frequency ($f_{TX\text{-}TANK}$) is also set at 240kHz. The transmit coil (L_{TX}) used in the example is 6.5µH. The value of transmit tank capacitance (C_{TX}) can be calculated:

$$C_{TX} = \frac{1}{4 \bullet \pi^2 \bullet f_{TX-TANK}^2 \bullet L_{TX}} = 66nF$$

   The recommended rating for C_{TX} capacitors in this particular example is 100V with 5% (or better) tolerance.

3. Determine the minimum pulse width of the transmitter driver required to deliver the required power at the receiver under the worst-case coupling conditions with maximum load.

   With L_{RX}, C_{RX}, L_{TX} and C_{TX} as determined above, place the receiver circuit in the worst-case coupling condition (largest gap between the T_X and R_X coils) with the battery at 4.1V (highest battery voltage in CC mode → highest output power). In this particular example, the worst-case coupling condition is set to be a 5.5mm separation with the two coils placed in a concentric configuration. Measure I_{IN} and I_{BAT} while varying the DC voltage on the PTH pins (V_{PTH}) of the transmitter. Figure 21 shows the plot of these measurements for this particular example.

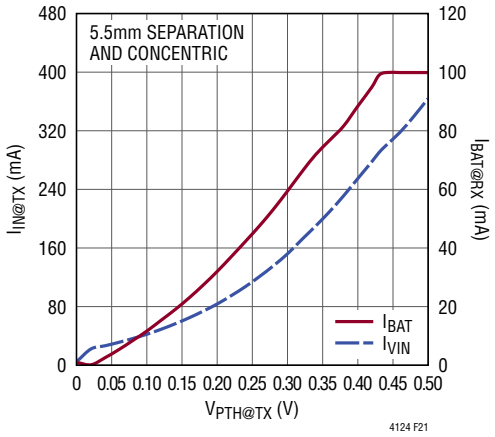


Figure 21. I_{IN} and I_{BAT} vs V_{PTH}

From Figure 21, the minimum voltage required at V_{PTH} (V_{PTHM})for the receiver to have the full charge current is 0.43V. This corresponds to 13% duty cycle at the driving voltage across the switch pins of the transmitter circuit.

APPLICATIONS INFORMATION

4. Verify that at the minimum pulse width selected in Step 3, the AC current through the transmit coil is well within its rating and that there is no excessive heating on the LTC4124 nor excessive negative voltage on the ACIN pin of the LTC4124.

   With the minimum pulse width determined in the previous step, place the receiver circuit at the best-case coupling condition (In this particular example, the best coupling condition is set to be 1.5mm separation with the T_X and R_X coils placed in a concentric configuration.) with the battery pin set at 4.3V (zero charge current→ lowest output power). Measure $I_{L\text{-}TX(RMS)}$, $\Delta T_{LTC4124}$ and $V_{ACIN\text{-}MIN}$. With V_{PTH} = 0.43V (from the previous step) and V_{BAT} = 4.3V, at the best-case coupling condition and steady state, the measured parameters are as follows:

   $I_{L\text{-}TX(RMS)}$ = 1.0A, $\Delta T_{LTC4124}$ = 32°C and $V_{ACIN\text{-}MIN}$ = –8.5V. The $I_{L\text{-}TX(RMS)}$ is well below the 2.5A max rated current for the transmit coil (see the Wurth Elektonik 760308101104 data sheet for more information). The temperature rise of 32°C and the minimum negative voltage on the ACIN pin are well within the rated operating condition for the LTC4124.

   This result is verified using the alternative formula provided in the Choosing Transmit Power Level section. Using the suggested method, the coupling value at the best coupling condition is 0.5. Using this coupling value, the predicted value of the minimum negative voltage developed on the ACIN is –8.5V. Therefore, the predicted maximum $V_{VCC} – V_{ACIN}$ is 14V as verified empirically.

5. Determine the values of R_{PTHM1} and R_{PTHM2} based on the minimum pulse width of the transmitter driver obtained in Step 3.

   Set R_{PTHM1} = 100kΩ. R_{PTHM2} can be obtained using the following formula:

$$R_{PTHM2} = \frac{\left\lfloor \frac{32 \bullet V_{PTHM}}{2.4} \right\rfloor + 0.5}{32 - \left(\left\lfloor \frac{32 \bullet V_{PTHM}}{2.4} \right\rfloor + 0.5 \right)} \bullet R_{PTHM1}$$

$$= 20.8k\Omega$$

$$\approx 21k\Omega \text{ (standard 1\% resistor value)}$$

   Note the quantity in the floor function brackets should be rounded down to the nearest integer.

6. Determine the values of R_{IS}, R_{IN}, R_{IMON} and C_{IMON} for load detection at best coupling with minimum load.

   With the same setup used in Step 4 and V_{BAT} = 4.3V, the input current to the transmit board is measured as I_{IN} = 240mA (I_{TH}). With the voltage drop across the sense resistor R_{IS} set to about 40mV, calculate R_{IS} according to the following formula:

$$R_{IS} = \frac{40mV}{I_{IN}} = \frac{40mV}{240mA} = 167m\Omega$$

$$\approx 180m\Omega \text{ (standard 1\% sense resistor value)}$$

   R_{IN} is set to be 374Ω such that with 40mV across R_{IS}, the IMON pin will source 107µA. This source current biases D_{IMON} to generate 1V at the IMON pin for load detection. C_{IMON} is set to be 10nF to provide some filtering on the IMON pin voltage, and R_{IMON} is set to 100kΩ to discharge C_{IMON} when the source current on the IMON pin is not present.

APPLICATIONS INFORMATION

7. Determine the value of C_{TS} for step duration during the LTC4125 load detection.

   Set the step duration to 50ms, approximately about 5 times the observed V_{IMON} settling time.

$$C_{TS} = 5 \bullet \frac{10\mu A \bullet T_S}{32 \bullet 1.2V} = 1.3 \times 10^{-6} \bullet T_S(s)$$

$$\approx 15nF \text{ (standard capacitor value)}$$

8. Determine the value of R_{FB1} and R_{FB2} for no receiver detection.

   With the minimum pulse width as determined in Step 3 and no receiver, measure I_{IN} and V_{LC-TX} amplitude. In this particular example, with no R_X present, at V_{PTH} = 0.43V: I_{IN} = 580mA and $|V_{LC-TX}|$ = 40V.

   The same measurement is done with a receiver at the worst coupling condition (largest gap between the T_X and R_X coils) with the battery pin set at 4.3V (zero charge current → lowest output power). In this particular example, using setup 4 at V_{PTH} = 0.43V, I_{IN} = 450mA and $|V_{LC-TX}|$ = 25V .

   At the V_{PTH} determined in step 3, the voltage at the transmitter resonant tank with no receiver is 40V ($V_{LC-TX-MAX}$), and with a receiver at minimum load, it is 25V ($V_{LC-TX-MIN}$). Using the formula provided in the LTC4125 data sheet, R_{FB1} and R_{FB2} can be calculated as follows:

$$\frac{V_{LC-TX-MIN} - V_D}{V_{IN}} - 1 < \frac{R_{FB1}}{R_{FB2}} < \frac{V_{LC-TX-MAX} - V_D}{V_{IN}} - 1$$

$$\frac{25V - 1V}{5V} - 1 < \frac{R_{FB1}}{R_{FB2}} < \frac{40V - 1V}{5V} - 1$$

$$3.8 < \frac{R_{FB1}}{R_{FB2}} < 6.8$$

   Therefore, set the ratio to be 6. Since the recommended total R_{FB1} + R_{FB2} resistance is about 100kΩ, set R_{FB1} = 100kΩ and R_{FB2} = 16.5kΩ.

9. Determine the value of R_{FTH1} and R_{FTH2} for foreign object detection.

   As outlined in steps 1 and 2, the resonant frequency selected is 240kHz. However, the operating frequency of the two coupled resonant LC at the T_X and R_X under heavy load at the best coupling condition is as high as 300kHz. Therefore, set the foreign object detection frequency threshold at 310kHz, about 3% above the highest operating frequency. Set R_{FTH2} = 100kΩ and R_{FTH1} according to the following formula:

$$R_{FTH1} = \left(\frac{320kHz}{f_{LIM}} - 1\right) \bullet R_{FTH2}$$

$$= \left(\frac{320kHz}{310kHz} - 1\right) \bullet 100k\Omega = 3.23k\Omega$$

$$\approx 3.24k\Omega \text{ (standard 1\% resistor value)}$$

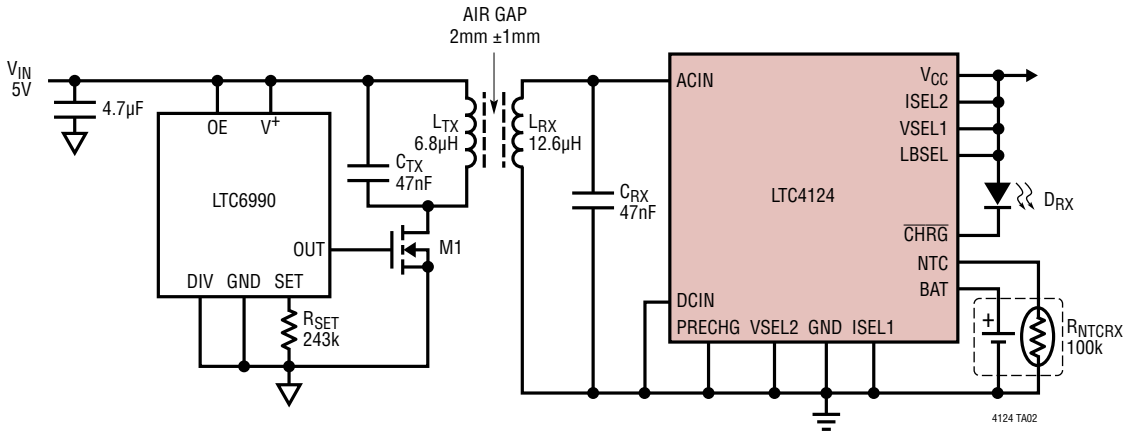
10. Determine the value of C_{TD} for the delay between each load detection attempt.

    Set the wait time to 5 seconds. Then, the C_{TD} value is calculated using the following formula:

$$C_{TD} = \frac{10\mu A \bullet T_D}{65 \times 10^3 \bullet 1.2V} = 1.3 \times 10^{-10} \bullet 5 \approx 680pF$$

TYPICAL APPLICATIONS

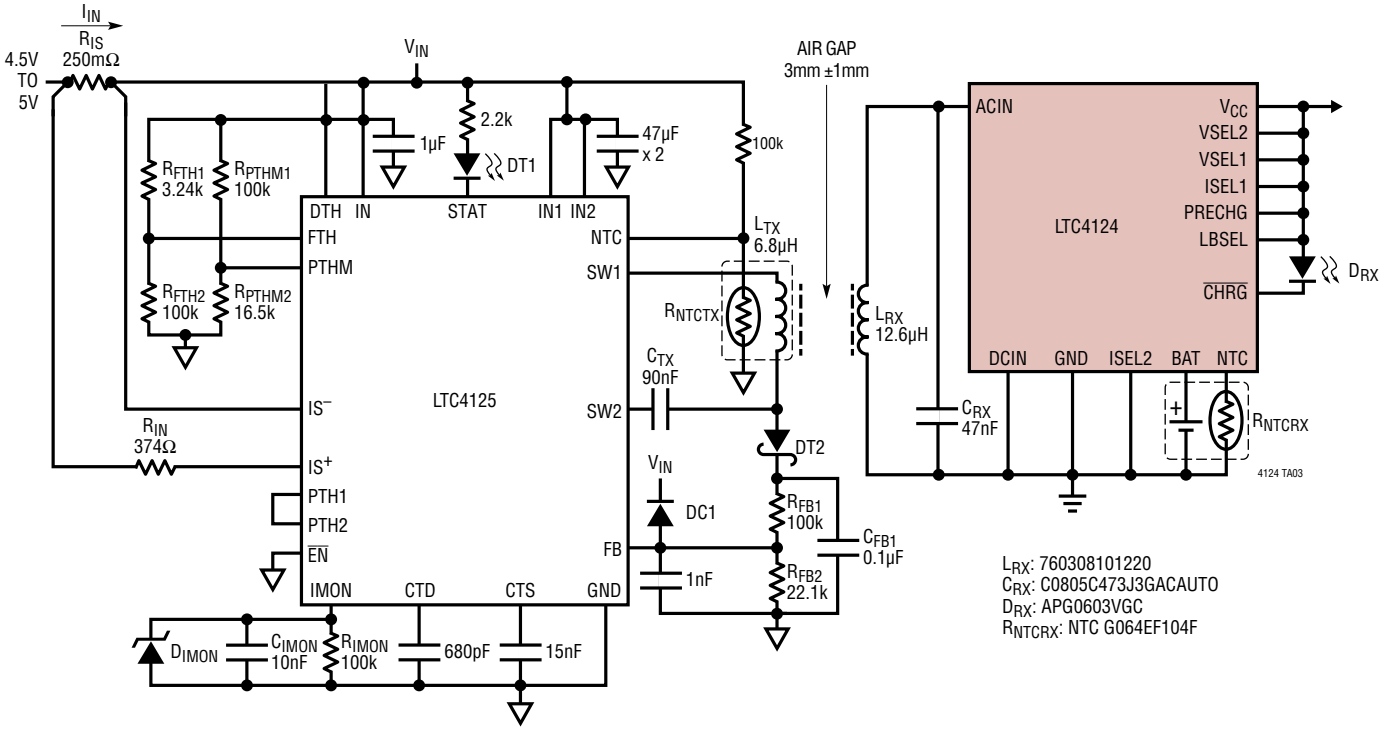
25mA LTC4124 Charger Receiver Using a 10mm R_X Coil Paired with a Simple Single Transistor Transmitter



M1: INFINEON, BSS816NW
C_{TX}: MURATA GCJ188R92A473KA01D
L_{TX}: WURTH, 760308101104

C_{RX}: MURATA, GCM155R71H473KE02J
L_{RX}: WURTH, 760308101208
D_{RX}: KINGBRIGHT, APG0603VGC
R_{NTCRX}: MURATA, NCP03WF104F

50mA LTC4124 Charger Receiver Paired with LTC4125 AutoResonant Transmitter

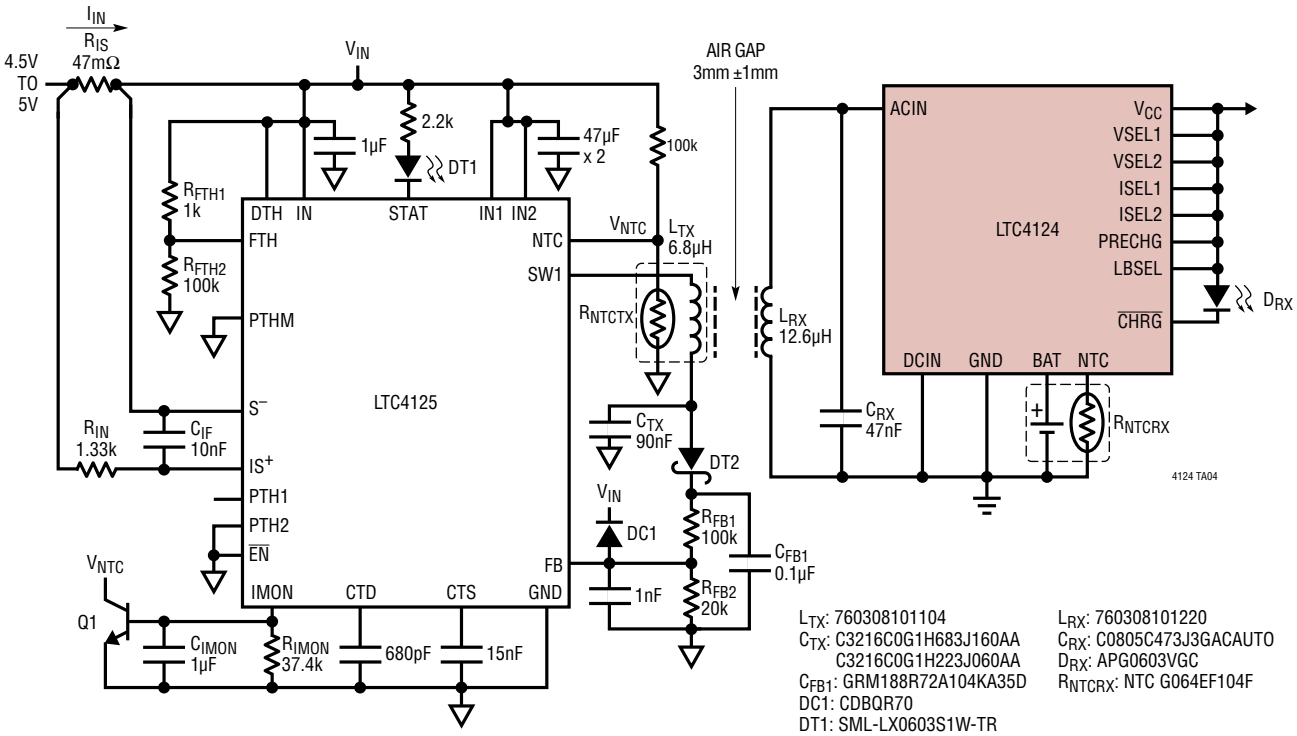


L_{TX}: 760308101104
C_{TX}: C3216C0G1H683J160AA, C3216C0G1H223J060AA
C_{FB1}: GRM188R72A104KA35D
DC1: CDBQR70
D_{IMON}: ADR510ARTZ
DT1: SML-LX0603S1W-TR
DT2: BAS521-7
R_{NTCTX}: NTC G064EF104F

L_{RX}: 760308101220
C_{RX}: C0805C473J3GACAUTO
D_{RX}: APG0603VGC
R_{NTCRX}: NTC G064EF104F

TYPICAL APPLICATIONS

100mA Charger Receiver Paired with LTC4125 AutoResonant Transmitter in Optimum Power Search Operation (LTC4125 Configured as Half-Bridge Resonant Driver)

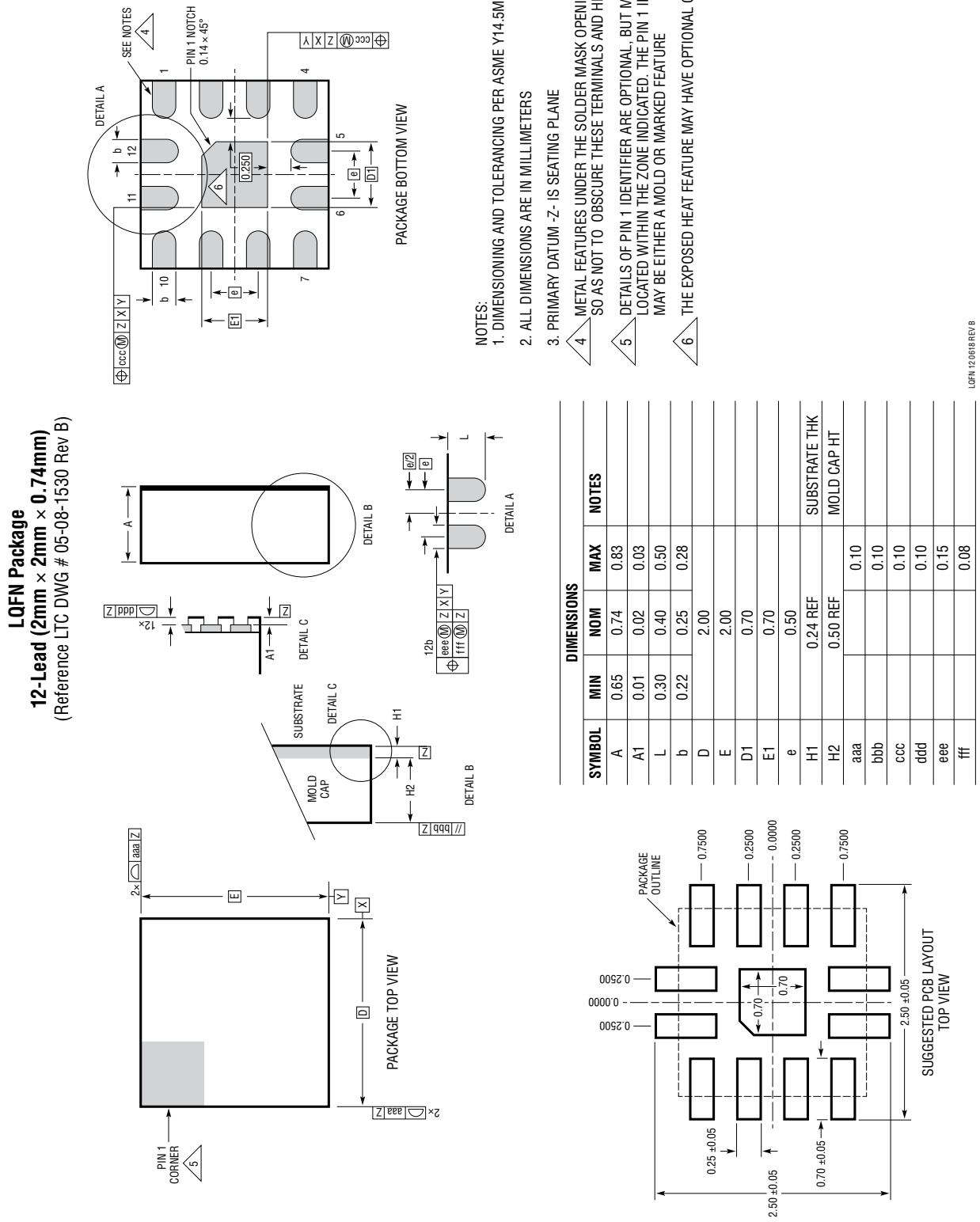


L_{TX}: 760308101104
C_{TX}: C3216C0G1H683J160AA
C3216C0G1H223J060AA
C_{FB1}: GRM188R72A104KA35D
DC1: CDBQR70
DT1: SML-LX0603S1W-TR
DT2: BAS521-7
R_{NTCTX}: NTC G064EF104F
Q1: PMBT3904M

L_{RX}: 760308101220
C_{RX}: C0805C473J3GACAUTO
D_{RX}: APG0603VGC
R_{NTCRX}: NTC G064EF104F

PACKAGE DESCRIPTION

LQFN Package
12-Lead (2mm × 2mm × 0.74mm)
(Reference LTC DWG # 05-08-1530 Rev B)



NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994
2. ALL DIMENSIONS ARE IN MILLIMETERS
3. PRIMARY DATUM -Z- IS SEATING PLANE
4. METAL FEATURES UNDER THE SOLDER MASK OPENING NOT SHOWN SO AS NOT TO OBSCURE THESE TERMINALS AND HEAT FEATURES
5. DETAILS OF PIN 1 IDENTIFIER ARE OPTIONAL, BUT MUST BE LOCATED WITHIN THE ZONE INDICATED. THE PIN 1 IDENTIFIER MAY BE EITHER A MOLD OR MARKED FEATURE
6. THE EXPOSED HEAT FEATURE MAY HAVE OPTIONAL CORNER RADII

DIMENSIONS				
SYMBOL	MIN	NOM	MAX	NOTES
A	0.65	0.74	0.83	
A1	0.01	0.02	0.03	
L	0.30	0.40	0.50	
b	0.22	0.25	0.28	
D		2.00		
E		2.00		
D1		0.70		
E1		0.70		
e		0.50		
H1		0.24 REF		SUBSTRATE THK
H2		0.50 REF		MOLD CAP HT
aaa			0.10	
bbb			0.10	
ccc			0.10	
ddd			0.10	
eee			0.15	
fff			0.08	

LQFN 12 0618 REV B

Rev. A

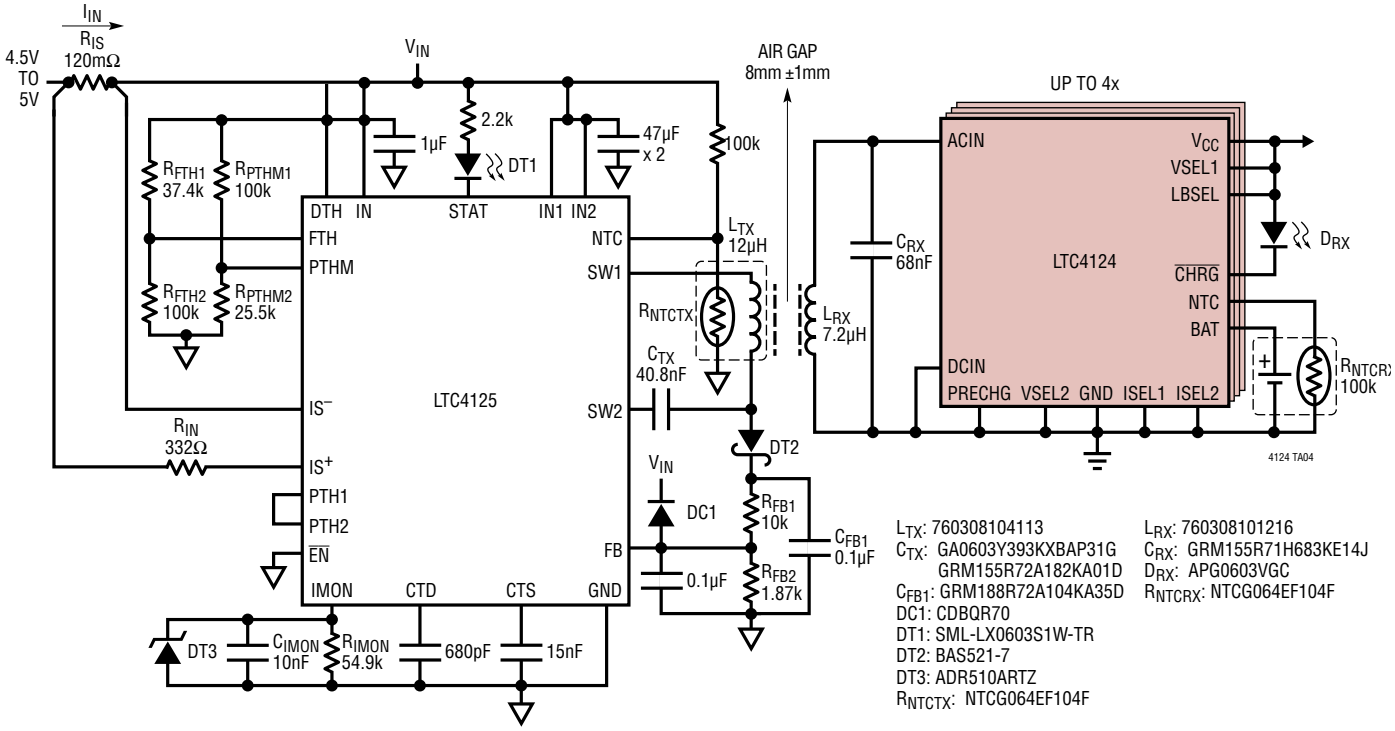
REVISION HISTORY

REV	DATE	DESCRIPTION	PAGE NUMBER
A	11/19	Changed Battery Charging V_{UVCL} Condition	3
		Changed Battery Discharge PowerPath Forward Regulation Voltage Condition	4
		Changed Disconnect Battery Leakage Curve Conditions	5
		Changed Application Circuits Cap Values	26, 27

Information furnished by Analog Devices is believed to be accurate and reliable. However, no responsibility is assumed by Analog Devices for its use, nor for any infringements of patents or other rights of third parties that may result from its use. Specifications subject to change without notice. No license is granted by implication or otherwise under any patent or patent rights of Analog Devices.

TYPICAL APPLICATION

Up to Four LTC4124, 10mA Minimum Size Charger Receivers with a Single LTC4125 AutoResonant Transmitter



L_{TX}: 760308104113
C_{TX}: GA0603Y393KXBAP31G
GRM155R72A182KA01D
C_{FB1}: GRM188R72A104KA35D
DC1: CDBQR70
DT1: SML-LX0603S1W-TR
DT2: BAS521-7
DT3: ADR510ARTZ
R_{NTCTX}: NTCG064EF104F

L_{RX}: 760308101216
C_{RX}: GRM155R71H683KE14J
D_{RX}: APG0603VGC
R_{NTCRX}: NTCG064EF104F

RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LTC4123	Low Power Wireless Charger for Hearing Aids	Wireless NiMH Charger, Temperature Compensated Charge Voltage, 1.5V at 25°C, 25mA Charge Current, 2mm × 2mm DFN-6 Package.
LTC4126	Low Power Li-Ion Wireless Charger with Step Down Regulator for Hearing Aids	Wireless Single Cell Li-Ion Charger, Internal Temperature Qualified Charging, 4.2V at 25°C, 7.5mA Charge Current, Integrated High Efficiency 1.2V Regulator, 2mm × 2mm LQFN Package.
LTC4070	Li-Ion/Polymer Shunt Battery Charger System	Low Operating Current (450nA), 1% Float Voltage Accuracy Over Full Temperature and Shunt Current Range, 50mA Maximum Internal Shunt Current (500mA with External PFET), Pin-Selectable Float Voltages: 4.0V, 4.1V, 4.2V. Ultralow Power Pulsed NTC Float Conditioning for Li-Ion/Polymer Protection, 8-Lead 2mm × 3mm DFN and MSOP.
LTC4071	Li-Ion/Polymer Shunt Battery Charger System with Low Battery Disconnect	Integrated Pack Protection, <10nA Low Battery Disconnect Protects Battery from Over-Discharge. Low Operating Current (550nA), 1% Float Voltage Accuracy Over Full Temperature and Shunt Current Range, 50mA Maximum Internal Shunt Current, Pin-Selectable Float Voltages: 4.0V, 4.1V, 4.2V. Ultralow Power Pulsed NTC Float Conditioning for Li-Ion/Polymer Protection, 8-Lead 2mm × 3mm DFN and MSOP.
LTC6990	TimerBlox: Voltage-Controlled Silicon Oscillator	Fixed-Frequency or Voltage-Controlled Operation.
LTC4125	5W AutoResonant Wireless Power Transmitter	Monolithic AutoResonant™ Full Bridge Driver. Transmit Power Automatically Adjusts to Receiver Load, Foreign Object Detection, Wide Operating Switching Frequency Range: 50kHz-250kHz, Input Voltage Range 3V to 5.5V, 20-Lead 4mm × 5mm QFN Package.
LTC4120	Wireless Power Receiver and 400mA Buck Battery Charger	Wireless 1 to 2 Cell Li-Ion Charger, 400mA Charge Current, Dynamic Harmonization Control, Wide Input Range: 12.5V – 40V, 3mm × 3mm QFN-16 Package.

© ANALOG DEVICES, INC. 2019

Mouser Electronics

Authorized Distributor

Click to View Pricing, Inventory, Delivery & Lifecycle Information:

Analog Devices Inc.:

LTC4124EV#TRMPBF LTC4124EV#TRPBF DC2770A-B-KIT DC2769A-A-KIT DC2770A-A-KIT DC2769A-B-KIT