

BQ51013C: Highly Integrated Wireless Receiver Qi (WPC v1.3) Compliant Power Supply

1 Features

- Integrated wireless power supply receiver solution
 - 93% overall peak AC-DC efficiency
 - Full synchronous rectifier
 - WPC v1.3 compliant communication control
 - Output voltage conditioning
 - Only IC required between Rx coil and output
- Wireless power consortium (WPC) v1.3 compliant (FOD enabled) highly accurate current sense
- Adaptive communication limit for robust communication
- Supports 20V maximum input
- Low-power dissipative rectifier overvoltage clamp ($V_{OVP} = 15V$)
- Thermal shutdown
- Multifunction NTC and control pin for temperature monitoring, charge complete, and fault host control

2 Applications

- WPC v1.3 compliant receivers
- Ultrasound smart probe
- Headsets/headphones & earbuds
- Cell phones and smart phones
- Headsets
- Handheld devices

3 Description

The BQ51013C device is a single-chip, advanced, flexible, secondary-side device for wireless power transfer in portable applications capable of providing up to 5W. The BQ51013C devices provide the receiver (RX) AC-to-DC power conversion and regulation while integrating the digital control required to comply with the Wireless Power Consortium (WPC) Qi v1.3 communication protocol. Together with the BQ500212A primary-side controller (or other Qi transmitter), the BQ51013C enables a complete contactless power transfer system for a wireless power supply solution. Global feedback is established from the secondary to the primary to control the power transfer process using the Qi v1.3 protocol.

The BQ51013C integrates a low-resistance synchronous rectifier, low-dropout regulator (LDO), digital control, and accurate voltage and current loops to ensure high efficiency and low power dissipation.

Package Information

PART NUMBER	PACKAGE ⁽¹⁾	PACKAGE SIZE ⁽²⁾	BODY SIZE (NOM)
BQ51013C	RHL (VQFN 20)	4.50mm × 3.50mm	4.50mm × 3.50mm

- For all available packages, see [Section 14](#).
- The package size (length × width) is a nominal value and includes pins, where applicable.

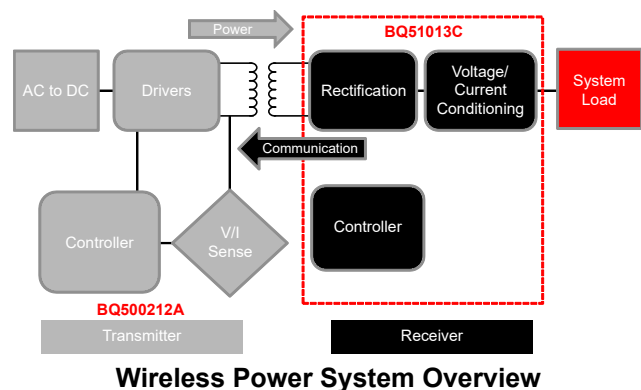
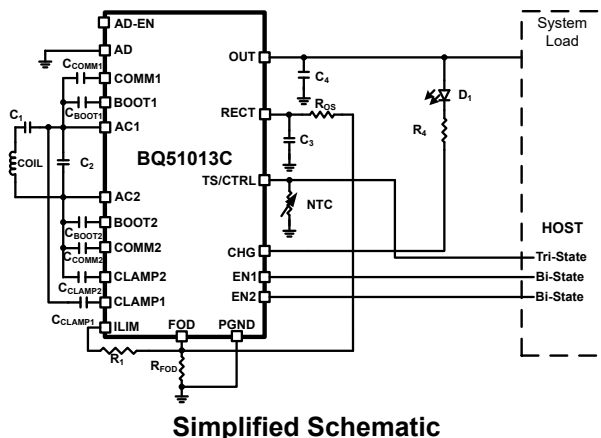


Table of Contents

1 Features	1	9 Application and Implementation	28
2 Applications	1	9.1 Application Information.....	28
3 Description	1	9.2 Typical Applications.....	28
4 Description (continued)	3	10 Power Supply Recommendations	36
5 Device Comparison Table	4	11 Layout	36
6 Pin Configuration and Functions	5	11.1 Layout Guidelines.....	36
7 Specifications	7	11.2 Layout Example.....	37
7.1 Absolute Maximum Ratings.....	7	12 Device and Documentation Support	38
7.2 ESD Ratings.....	7	12.1 Device Support.....	38
7.3 Recommended Operating Conditions.....	7	12.2 Receiving Notification of Documentation Updates..	38
7.4 Thermal Information.....	7	12.3 Support Resources.....	38
7.5 Electrical Characteristics.....	8	12.4 Trademarks.....	38
7.6 Typical Characteristics.....	11	12.5 Electrostatic Discharge Caution.....	38
8 Detailed Description	15	12.6 Glossary.....	38
8.1 Overview.....	15	13 Revision History	38
8.2 Functional Block Diagram.....	16	14 Mechanical, Packaging, and Orderable	
8.3 Feature Description.....	16	Information	39
8.4 Device Functional Modes.....	27		

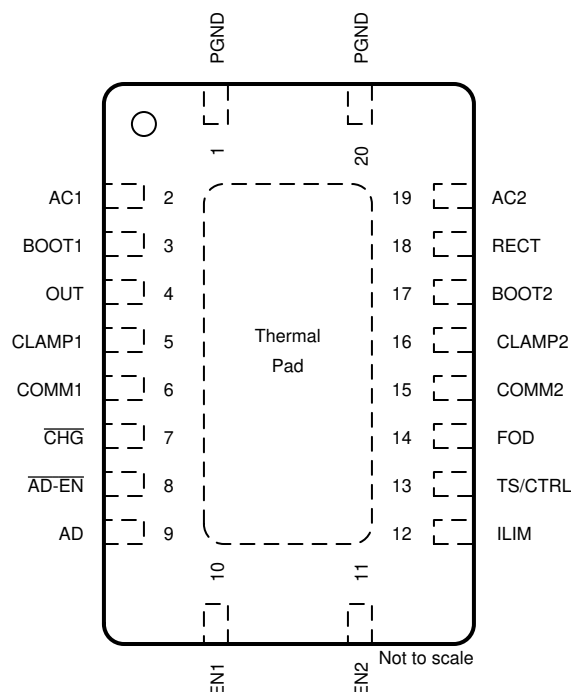
4 Description (continued)

The BQ51013C also includes a digital controller that calculates the amount of power received by the mobile device within the limits set by the WPC v1.3 standard. The controller then communicates this information to the transmitter (TX) to allow the TX to determine if a foreign object is present within the magnetic interface and introduces a higher level of safety within magnetic field. This Foreign Object Detection (FOD) method is part of the requirements under the WPC v1.3 specification.

5 Device Comparison Table

DEVICE	FUNCTION	V_{OUT} ($V_{BAT-REG}$)	MAXIMUM P_{OUT}	I ² C
BQ51003	Wireless Receiver	5 V	2.5 W	No
BQ51013B	Wireless Receiver	5 V	5 W	No
BQ51013B-Q1	Automotive Wireless Receiver	5 V	5 W	No
BQ51013C-Q1	Automotive Wireless Receiver	5 V	5 W	No
BQ51013C	Wireless Receiver	5 V	5 W	No
BQ51020	Wireless Receiver	4.5 to 8 V	5 W	No
BQ51021	Wireless Receiver	4.5 to 8 V	5 W	Yes
BQ51050B	Wireless Receiver and Direct Charger	4.2 V	5 W	No
BQ51051B	Wireless Receiver and Direct Charger	4.35 V	5 W	No
BQ51052B	Wireless Receiver and Direct Charger	4.4 V	5 W	No

6 Pin Configuration and Functions



A. The exposed thermal pad should be connected to ground.

Figure 6-1. RHL Package 20-Pin VQFN Top View

Table 6-1. Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
AC1	2	I	AC input from receiver coil.
AC2	19	I	
AD	9	I	If AD functionality is used, connect this pin to the wired adapter input. When V_{AD_Pres} is applied to this pin wireless charging is disabled and $\overline{AD_EN}$ is driven low. Connect a 1- μ F capacitor from AD to PGND. If unused, the capacitor is not required and AD should be connected directly to PGND.
$\overline{AD_EN}$	8	O	Push-pull driver for external PFET when wired charging is active. Float if not used.
BOOT1	3	O	Bootstrap capacitors for driving the high-side FETs of the synchronous rectifier. Connect a 10-nF ceramic capacitor from BOOT1 to AC1 and from BOOT2 to AC2.
BOOT2	17	O	
CHG	7	O	Open-drain output – active when OUT is enabled. Float or tie to PGND if unused.
CLAMP2	16	O	Open-drain FETs which are used for a non-power dissipative overvoltage AC clamp protection. When the RECT voltage goes above 15 V, both switches will be turned on and the capacitors will act as a low impedance to protect the device from damage. If used, capacitors are used to connect CLAMP1 to AC1 and CLAMP2 to AC2. Recommended connections are 0.47- μ F capacitors.
CLAMP1	5	O	
COMM1	6	O	Open-drain outputs used to communicate with primary by varying reflected impedance. Connect a capacitor from COMM1 to AC1 and a capacitor from COMM2 to AC2 for capacitive load modulation. For resistive modulation connect COMM1 and COMM2 to RECT through a single resistor. See Section 8.3.8 for more information.
COMM2	15	O	
EN1	10	I	Inputs that allow user to enable and disable wireless and wired charging <EN1 EN2>: <00> Wireless charging is enabled unless AD voltage > V_{AD_Pres} . <01> Dynamic communication current limit disabled. <10> $\overline{AD_EN}$ pulled low, wireless charging disabled. <11> Wired and wireless charging disabled.
EN2	11	I	
FOD	14	I	

Table 6-1. Pin Functions (continued)

PIN		I/O	DESCRIPTION
NAME	NO.		
ILIM	12	I/O	Programming pin for the over current limit. The total resistance from ILIM to GND (R_{ILIM}) sets the current limit. The schematic shown in Figure 9-1 illustrates the R_{ILIM} as $R_1 + R_{FOD}$. Details can be found in Section 7.5 and Figure 9-1 .
OUT	4	O	Output pin, delivers power to the load.
PGND	1, 20		Power ground
RECT	18	O	Filter capacitor for the internal synchronous rectifier. Connect a ceramic capacitor to PGND. Depending on the power levels, the value may be 4.7 μ F to 22 μ F.
TS/CTRL	13	I	Dual function pin: Temperature Sense (TS) and Control (CTRL) pin functionality. For the TS functionality connect TS/CTRL to ground through a Negative Temperature Coefficient (NTC) resistor. If an NTC function is not desired, connect to PGND with a 10-k Ω resistor. See Section 8.3.11 for more details. For the CTRL functionality pull below $V_{CTRL-Low}$ or pull above $V_{CTRL-High}$ to send an End Power Transfer Packet. See Table 8-3 for more details.
—	PAD	—	The exposed thermal pad should be connected to ground (PGND)

7 Specifications

7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)^{(1) (2)}

		MIN	MAX	UNIT
Input voltage	AC1, AC2	−0.8	20	V
	RECT, COMM1, COMM2, OUT, $\overline{\text{CHG}}$, CLAMP1, CLAMP2	−0.3	20	
	AD, $\overline{\text{AD-EN}}$	−0.3	30	
	BOOT1, BOOT2	−0.3	26	
	EN1, EN2 ⁽³⁾ , FOD, TS/CTRL, ILIM	−0.3	7	
Input current	AC1, AC2		2	A(RMS)
Output current	OUT		1.5	A
Output sink current	$\overline{\text{CHG}}$		15	mA
	COMM1, COMM2		1	A
Junction temperature, T_J		−40	150	°C
Storage temperature, T_{stg}		−65	150	°C

- (1) All voltages are with respect to the VSS terminal, unless otherwise noted.
(2) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(3) If EN1 or EN2 are subject to fast transient (>10V/10ns), current limiting resistors (1k to 10k ohms) should be added.

7.2 ESD Ratings

		VALUE	UNIT
$V_{\text{(ESD)}}$ Electrostatic discharge	Human body model (HBM), per AEC Q100-002 ⁽¹⁾	±2000	V
	Charged device model (CDM), per AEC Q100-011	±500	

- (1) AEC Q100-002 indicates that HBM stressing must be in accordance with the ANSI/ESDA/JEDEC JS-001 specification.

7.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

			MIN	MAX	UNIT
V_{RECT}	Voltage	RECT	4	7	V
I_{RECT}	Current through internal rectifier	RECT		1.5	A
I_{OUT}	Output current	OUT		1.5	A
V_{AD}	Adapter voltage	AD		15	V
$I_{\text{AD-EN}}$	Sink current	$\overline{\text{AD-EN}}$		1	mA
I_{COMM}	COMMx sink current	COMM1, COMM2		500	mA
T_J	Junction temperature		0	125	°C

7.4 Thermal Information

THERMAL METRIC ⁽¹⁾		BQ51013C	UNIT
		RHL (VQFN)	
		20 PINS	
$R_{\theta\text{JA}}$	Junction-to-ambient thermal resistance	37.2	°C/W
$R_{\theta\text{JC(top)}}$	Junction-to-case (top) thermal resistance	30.0	°C/W
$R_{\theta\text{JB}}$	Junction-to-board thermal resistance	14.0	°C/W

7.4 Thermal Information (continued)

THERMAL METRIC ⁽¹⁾		BQ51013C	UNIT
		RHL (VQFN)	
		20 PINS	
Ψ_{JT}	Junction-to-top characterization parameter	0.4	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	13.9	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	3.3	°C/W

(1) For more information about traditional and new thermal metrics, see the [Semiconductor and IC Package Thermal Metrics](#) application report.

7.5 Electrical Characteristics

over operating free-air temperature range, –40°C to 125°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{UVLO}	Undervoltage lockout	$V_{RECT}: 0\text{ V} \rightarrow 3\text{ V}$	2.5	2.7	2.8	V
$V_{HYS-UVLO}$	Hysteresis on UVLO	$V_{RECT}: 3\text{ V} \rightarrow 2\text{ V}$		0.25		V
$V_{RECT-OVP}$	Input overvoltage threshold	$V_{RECT}: 5\text{ V} \rightarrow 16\text{ V}$	14.5	15	15.5	V
$V_{HYS-OVP}$	Hysteresis on OVP	$V_{RECT}: 16\text{ V} \rightarrow 5\text{ V}$		0.15		V
$V_{RECT-Th4}$	Dynamic V_{RECT} Threshold 4	$I_{LOAD} > 0.4 \times I_{IMAX}$ (I_{LOAD} rising)		5.11		V
$V_{RECT-DPM}$	Rectifier undervoltage protection, restricts I_{OUT} at $V_{RECT-DPM}$		3	3.1	3.2	V
$V_{RECT-REV}$	Rectifier reverse voltage protection at the output	$V_{RECT-REV} = V_{OUT} - V_{RECT}$, $V_{OUT} = 10\text{ V}$	7	8	9	V
QUIESCENT CURRENT						
I_{RECT}	Active chip quiescent current consumption from RECT	$I_{LOAD} = 0\text{ mA}$, $0^\circ\text{C} \leq T_J \leq 85^\circ\text{C}$		8	10	mA
		$I_{LOAD} = 300\text{ mA}$, $0^\circ\text{C} \leq T_J \leq 85^\circ\text{C}$		2	3	mA
I_{OUT}	Quiescent current at the output when wireless power is disabled (Standby)	$V_{OUT} = 5\text{ V}$, $0^\circ\text{C} \leq T_J \leq 85^\circ\text{C}$		20	35	μA
ILIM SHORT CIRCUIT						
$R_{ILIM-SHORT}$	Highest value of I_{LIM} resistance to ground (R_{ILIM}) considered a fault (short). Monitored for $I_{OUT} > 100\text{ mA}$	$R_{ILIM}: 200\ \Omega \rightarrow 50\ \Omega$. I_{OUT} latches off, cycle power to reset			120	Ω
$t_{DGL-Short}$	Deglintch time transition from I_{LIM} short to I_{OUT} disable			1		ms
$I_{LIM_SHORT,OK}$	$I_{LIM_SHORT,OK}$ enables the I_{LIM} short comparator when I_{OUT} is greater than this value	$I_{LOAD}: 0\text{ mA} \rightarrow 200\text{ mA}$	116	145	165	mA
$I_{LIM_SHORT,OK\ HYST}$	Hysteresis for $I_{LIM_SHORT,OK}$ comparator	$I_{LOAD}: 0\text{ mA} \rightarrow 200\text{ mA}$		30		mA
I_{OUT}	Maximum output current limit, C_L	Maximum I_{LOAD} that will be delivered for 1 ms when I_{LIM} is shorted			2450	mA
OUTPUT						
$V_{OUT-REG}$	Regulated output voltage	$I_{LOAD} = 1000\text{ mA}$	4.92	5.00	5.04	V
		$I_{LOAD} = 10\text{ mA}$	4.94	5.01	5.06	
K_{ILIM}	Current programming factor for hardware protection	$R_{ILIM} = K_{ILIM} / I_{LIM}$, where I_{LIM} is the hardware current limit. $I_{OUT} = 1\text{ A}$	285	314	321	AΩ

7.5 Electrical Characteristics (continued)

over operating free-air temperature range, –40°C to 125°C (unless otherwise noted)

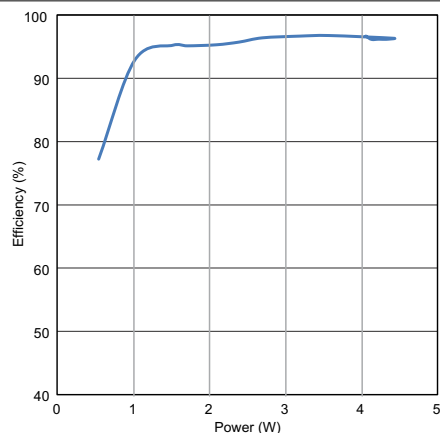
PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
K_{IMAX}	Current programming factor for the nominal operating current	$I_{IMAX} = K_{IMAX} / R_{ILIM}$ where I_{IMAX} is the maximum normal operating current. $I_{OUT} = 1\text{ A}$		262		AΩ
I_{OUT}	Current limit programming range				1500	mA
I_{COMM}	Current limit during WPC communication	$I_{OUT} > 300\text{ mA}$		$I_{OUT} + 50$		mA
		$I_{OUT} < 300\text{ mA}$	320	380	440	mA
t_{HOLD}	Hold off time for the communication current limit during start-up			1		s
TS / CTRL FUNCTIONALITY						
$V_{TS-Bias}$	Internal TS Bias Voltage (V_{TS} is the voltage at the TS/CTRL pin, $V_{TS-Bias}$ is that internal bias voltage)	$I_{TS-Bias} < 100\text{ }\mu\text{A}$ (periodically driven see $t_{TS/CTRL}$)	2	2.2	2.4	V
V_{COLD}	Rising threshold	$V_{TS-Bias}$: 50% → 60%	56.5	58.7	60.8	% $V_{TS-Bias}$
$V_{COLD-Hyst}$	Falling hysteresis	$V_{TS-Bias}$: 60% → 50%		2		% $V_{TS-Bias}$
V_{HOT}	Falling threshold	$V_{TS-Bias}$: 20% → 15%	18.5	19.6	20.7	% $V_{TS-Bias}$
$V_{HOT-Hyst}$	Rising hysteresis	$V_{TS-Bias}$: 15% → 20%		3		% $V_{TS-Bias}$
$V_{CTRL-High}$	Voltage on CTRL pin for a high		0.2		5	V
$V_{CTRL-Low}$	Voltage on CTRL pin for a low		0		0.05	mV
$t_{TS/CTRL-Meas}$	Time period of TS/CTRL measurements (when $V_{TS-Bias}$ is being driven internally)	Synchronous to the communication period		24		ms
$t_{TS-Deglintch}$	Deglintch time for all TS comparators			10		ms
R_{TS}	Pullup resistor for the NTC network. Pulled up to $V_{TS-Bias}$		18	20	22	kΩ
THERMAL PROTECTION						
T_{J-SD}	Thermal shutdown temperature			155		°C
T_{J-Hys}	Thermal shutdown hysteresis			20		°C
OUTPUT LOGIC LEVELS ON CHG						
V_{OL}	Open-drain \overline{CHG} pin	$I_{SINK} = 5\text{ mA}$			500	mV
I_{OFF}	\overline{CHG} leakage current when disabled	$V_{\overline{CHG}} = 20\text{ V}$			1	μA
COMM PIN						
$R_{DS(ON)}$	COMM1 and COMM2	$V_{RECT} = 2.6\text{ V}$		1.5		Ω
I_{OFF}	COMMx pin leakage current	$V_{COMM1} = 20\text{ V}$, $V_{COMM2} = 20\text{ V}$			1	μA
CLAMP PIN						
$R_{DS(ON)}$	CLAMP1 and CLAMP2			0.8		Ω
ADAPTER ENABLE						
$V_{AD-Pres}$	V_{AD} Rising threshold voltage	$V_{AD} 0\text{ V} \rightarrow 5\text{ V}$	3.5	3.6	3.8	V
$V_{AD-PresH}$	V_{AD} hysteresis	$V_{AD} 5\text{ V} \rightarrow 0\text{ V}$		400		mV
I_{AD}	Input leakage current	$V_{RECT} = 0\text{ V}$, $V_{AD} = 5\text{ V}$			60	μA
R_{AD}	Pullup resistance from $\overline{AD-EN}$ to OUT when adapter mode is disabled and $V_{OUT} > V_{AD}$, EN-OUT	$V_{AD} = 0\text{ V}$, $V_{OUT} = 5\text{ V}$		200	350	Ω
$V_{AD-Diff}$	Voltage difference between V_{AD} and $V_{\overline{AD-EN}}$ when adapter mode is enabled	$V_{AD} = 5\text{ V}$, $0^\circ\text{C} \leq T_J \leq 85^\circ\text{C}$	3	4.5	5	V
SYNCHRONOUS RECTIFIER						
I_{OUT-SR}	I_{OUT} at which the synchronous rectifier enters half-synchronous mode, SYNC_EN	$I_{LOAD} 200\text{ mA} \rightarrow 0\text{ mA}$	80	100	135	mA

7.5 Electrical Characteristics (continued)

over operating free-air temperature range, -40°C to 125°C (unless otherwise noted)

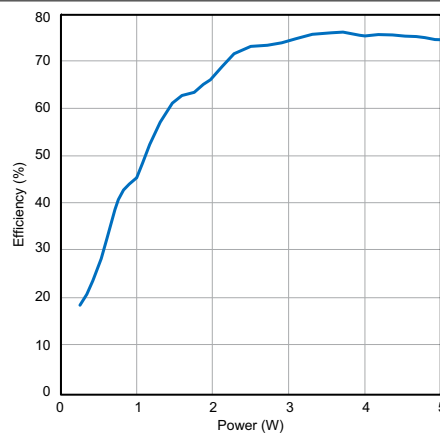
PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$I_{\text{OUT-SRH}}$	Hysteresis for $I_{\text{OUT,SR}}$ (full-synchronous mode enabled)	$I_{\text{LOAD}} 0 \text{ mA} \rightarrow 200 \text{ mA}$		30		mA
$V_{\text{HS-DIODE}}$	High-side diode drop when the rectifier is in half-synchronous mode	$I_{\text{AC-VRECT}} = 250 \text{ mA}$ and $T_J = 25^{\circ}\text{C}$		0.7		V
EN1 AND EN2						
V_{IL}	Input low threshold for EN1 and EN2				0.4	V
V_{IH}	Input high threshold for EN1 and EN2		1.3			V
R_{PD}	EN1 and EN2 pulldown resistance			200		k Ω
ADC (WPC RELATED MEASUREMENTS AND COEFFICIENTS)						
$I_{\text{OUT SENSE}}$	Accuracy of the current sense over the load range	$I_{\text{OUT}} = 750 \text{ mA} - 1000 \text{ mA}$	-1.5%	0%	0.9%	

7.6 Typical Characteristics



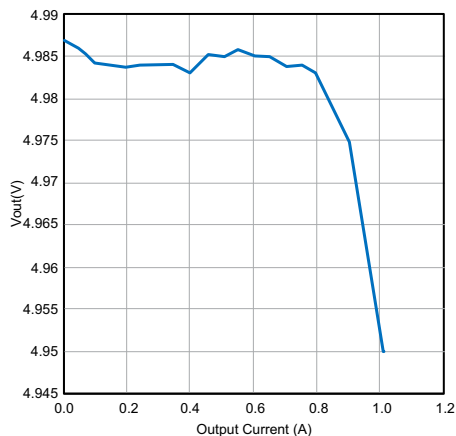
Input: RX AC power Output: RX RECT power
Efficiency: Output Power / Input Power

Figure 7-1. Rectifier Efficiency



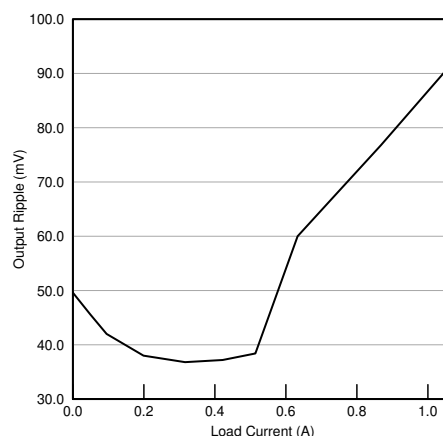
Input: TX DC power Output: RX RECT power
Efficiency: Output Power / Input Power

Figure 7-2. System Efficiency From DC Input to DC Output



Maximum Current = 1 A

Figure 7-3. Impact of Load Current on Output Voltage



$C_{OUT} = 1 \mu\text{F}$ Without Communication

Figure 7-4. Impact of Load Current on Output Ripple

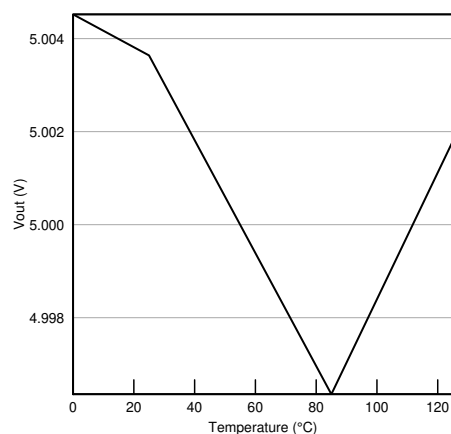


Figure 7-5. V_{OUT} vs Temperature

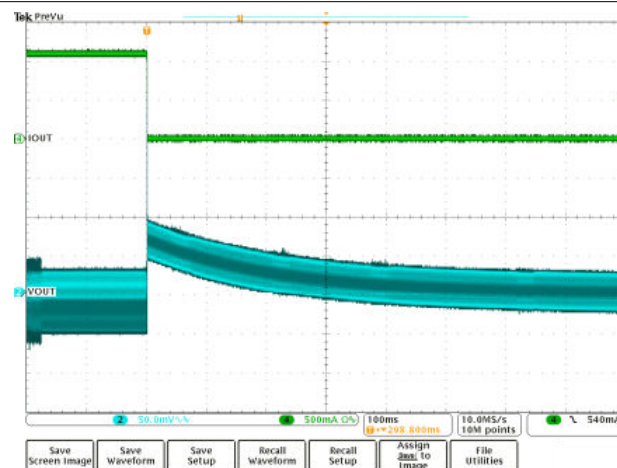


Figure 7-6. 1-A Instantaneous Load Dump (2)

7.6 Typical Characteristics (continued)

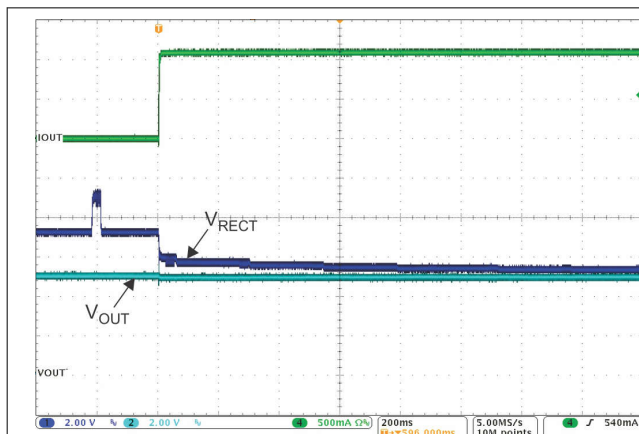


Figure 7-7. 1-A Load Step Full System Response

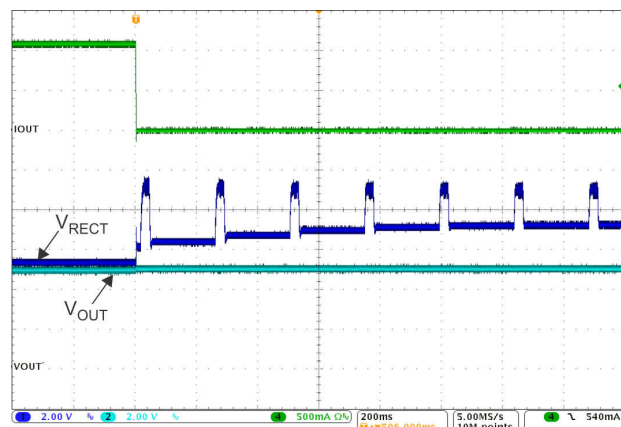


Figure 7-8. 1-A Load Dump Full System Response

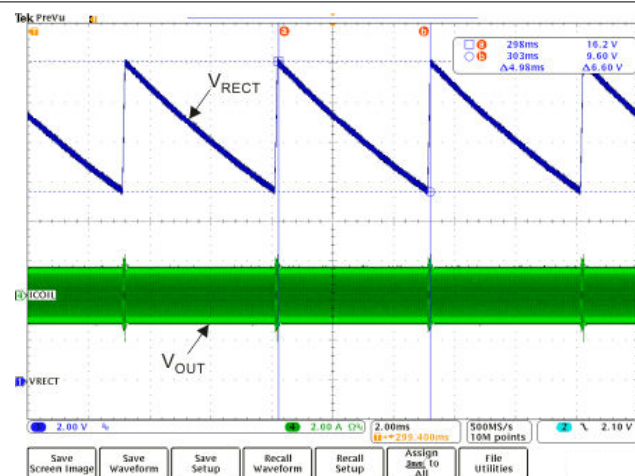
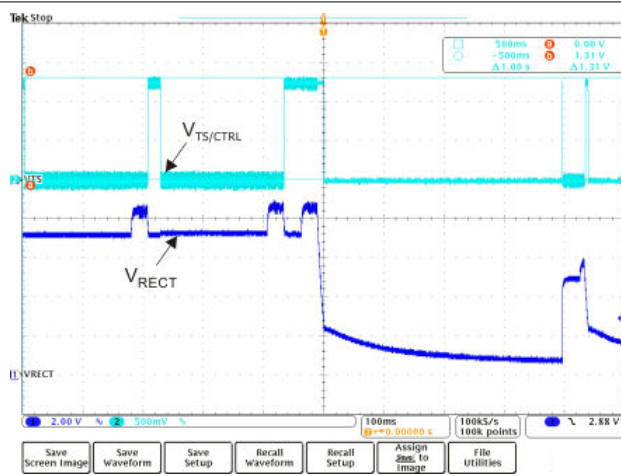
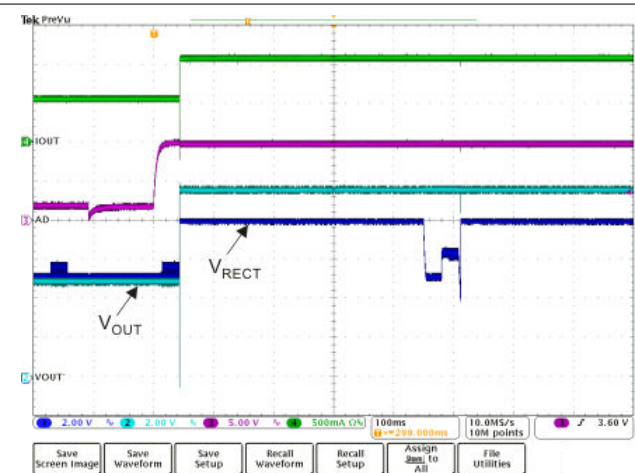
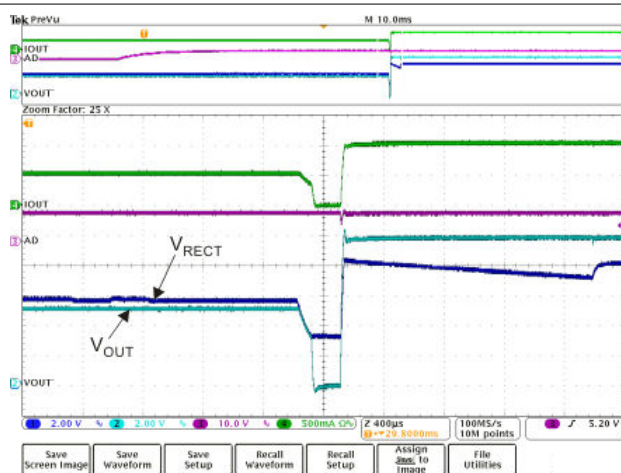
Figure 7-9. Rectifier Overvoltage Clamp ($f_{op} = 110$ kHz)

Figure 7-10. TS Fault

Figure 7-11. Adapter Insertion ($V_{AD} = 10$ V)Figure 7-12. Adapter Insertion ($V_{AD} = 10$ V) Illustrating Break-Before-Make Operation

7.6 Typical Characteristics (continued)

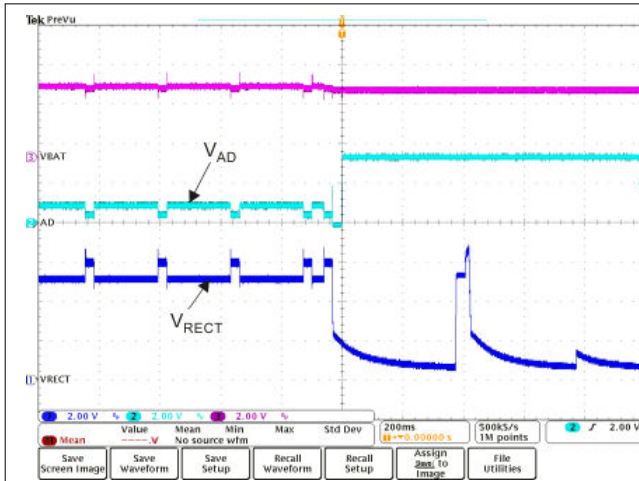


Figure 7-13. On-the-Go Enabled ($V_{OTG} = 3.5\text{ V}$) (3)

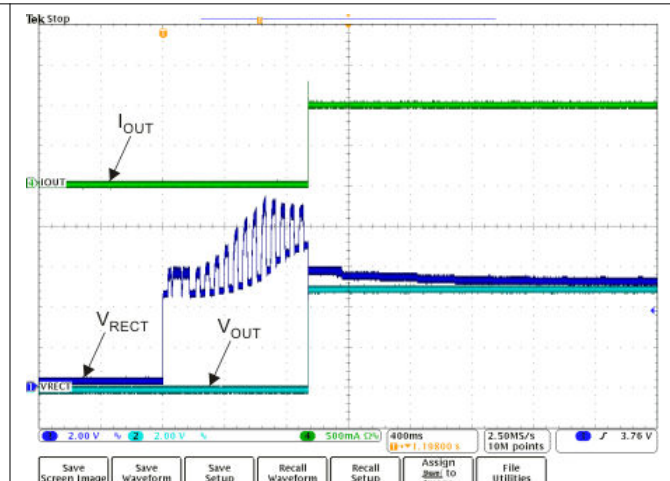


Figure 7-14. BQ51013C Typical Start-Up With a 1-A System Load

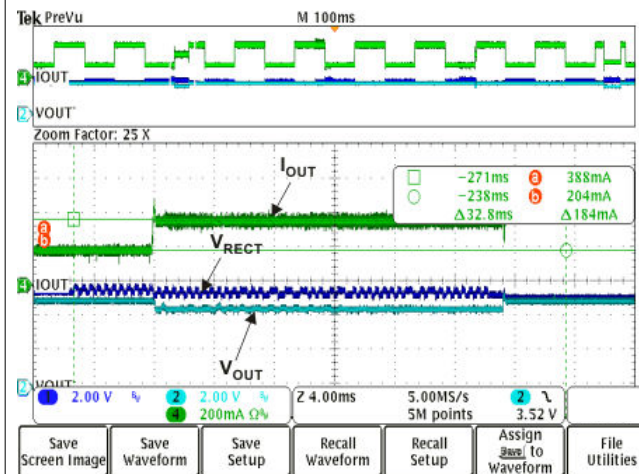


Figure 7-15. Adaptive Communication Limit Event Where the 400-mA Current Limit is Enabled ($I_{OUT-DC} < 300\text{ mA}$)

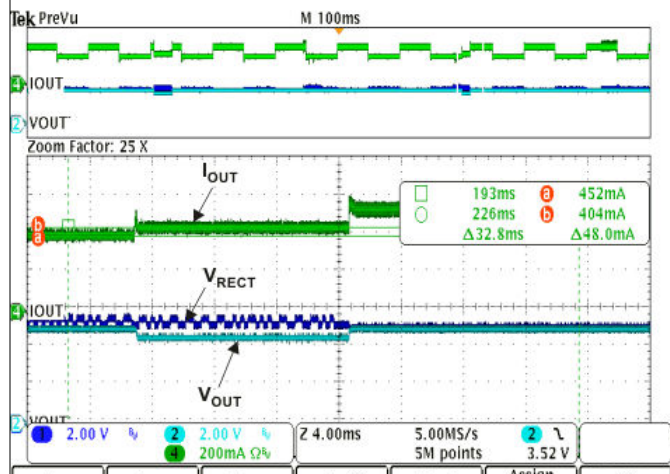
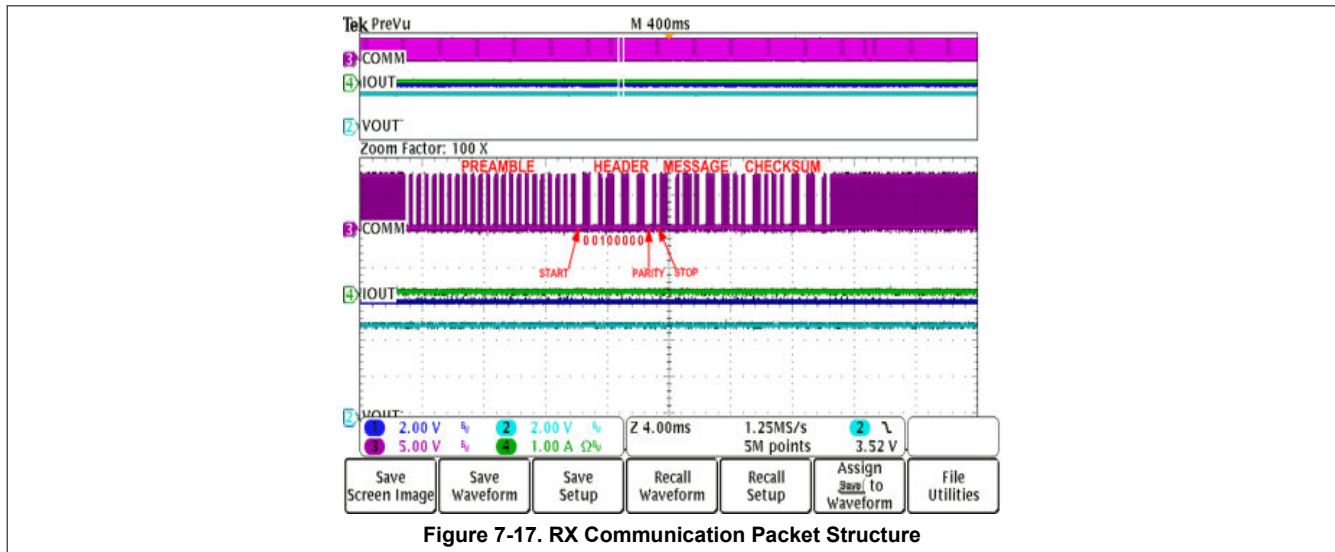


Figure 7-16. Adaptive Communication Limit Event Where the Current Limit is $I_{OUT} + 50\text{ mA}$ ($I_{OUT-DC} > 300\text{ mA}$)

7.6 Typical Characteristics (continued)



1. Efficiency measured from DC input to the transmitter to DC output of the receiver. The BQ500210EVM-689 TX was used for these measurements. Measurement subject to change if an alternate TX is used.
2. Total droop experienced at the output is dependent on receiver coil design. The output impedance must be low enough at that particular operating frequency in order to not collapse the rectifier below 5 V.
3. On-the-go mode is enabled by driving EN1 high. In this test, the external PMOS is connected between the output of the BQ51013C device and the AD pin; therefore, any voltage source on the output is supplied to the AD pin.

8 Detailed Description

8.1 Overview

A wireless system consists of a charging pad (transmitter, TX or primary) and the secondary-side equipment (receiver, RX or secondary). There is a coil in the charging pad and in the secondary equipment which are magnetically coupled to each other when the secondary is placed on the primary. Power is then transferred from the transmitter to the receiver through coupled inductors (effectively an air-core transformer). Controlling the amount of power transferred is achieved by sending feedback (error signal) communication to the primary (to increase or decrease power).

The receiver communicates with the transmitter by changing the load seen by the transmitter. This load variation results in a change in the transmitter coil current, which is measured and interpreted by a processor in the charging pad. The communication is digital; packets are transferred from the receiver to the transmitter. Differential bi-phase encoding is used for the packets. The bit rate is 2-kbps.

Various types of communication packets have been defined. These include identification and authentication packets, error packets, control packets, end power packets, and power usage packets.

The transmitter coil stays powered off most of the time. It occasionally wakes up to see if a receiver is present. When a receiver authenticates itself to the transmitter, the transmitter will remain powered on. The receiver maintains full control over the power transfer using communication packets.

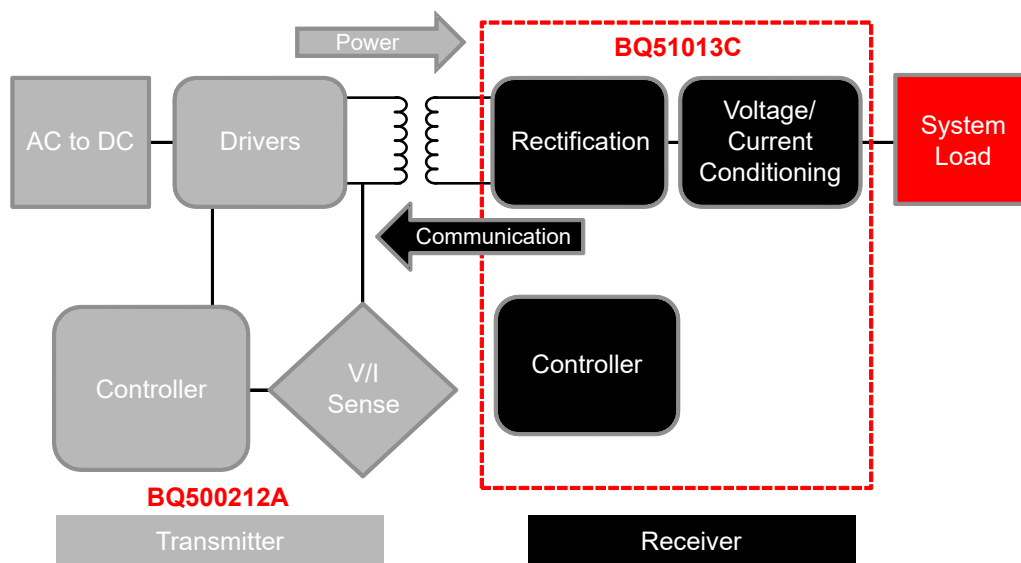
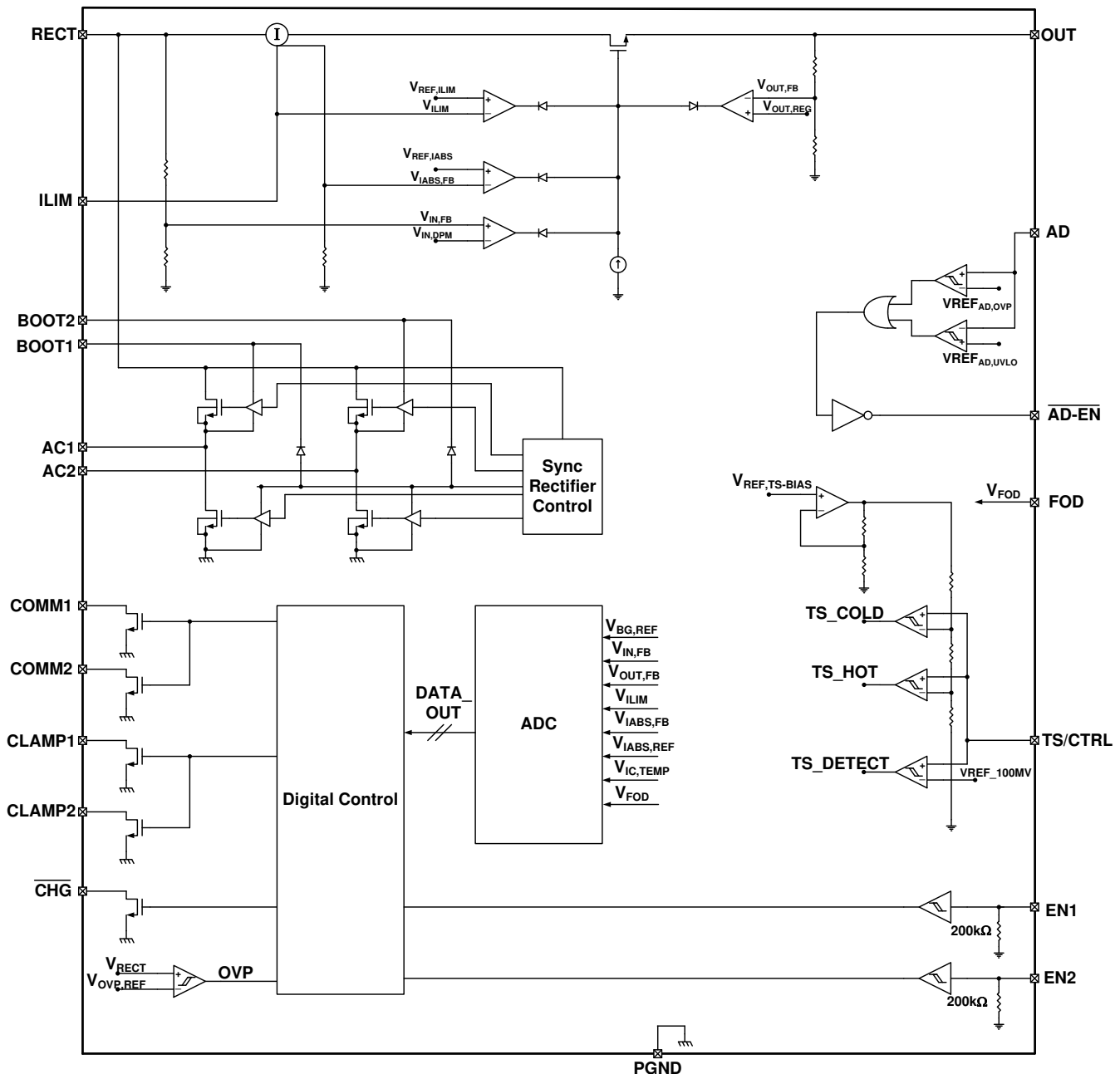


Figure 8-1. WPC Wireless Power System Indicating the Functional Integration of the BQ51013C

8.2 Functional Block Diagram



8.3 Feature Description

8.3.1 Details of a Qi Wireless Power System and BQ51013C Power Transfer Flow Diagrams

The BQ51013C integrates a fully compliant WPC v1.3 communication algorithm in order to streamline receiver designs (no extra software development required). This section provides a high level overview of these features by illustrating the wireless power transfer flow diagram from start-up to active operation.

During start-up operation, the wireless power receiver must comply with proper handshaking to be granted a power contract from the TX. The TX will initiate the handshake by providing an extended digital ping. If an RX is present on the TX surface, the RX will then provide the signal strength, configuration and identification packets to the TX (see volume 1 of the WPC specification for details on each packet). These are the first three packets sent to the TX. The only exception is if there is a true shutdown condition on the EN1/EN2, AD, or TS/CTRL

pins where the RX will shut down the TX immediately. See [Table 8-3](#) for details. Once the TX has successfully received the signal strength, configuration and identification packets, the RX will be granted a power contract and is then allowed to control the operating point of the power transfer. See [Figure 8-2](#) for the start-up flow diagram details.

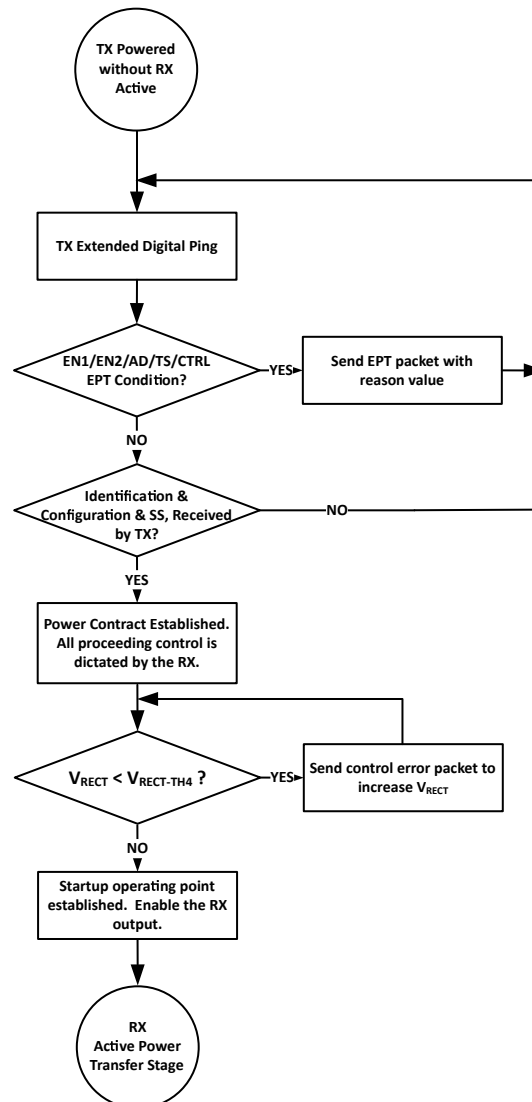


Figure 8-2. Wireless Power Start-Up Flow Diagram

Once the start-up procedure has been established, the RX enters the active power transfer stage. This is considered the “main loop” of operation. The RX sends control error packets in order to converge on these targets. As the output current changes, the rectifier voltage target will dynamically change. The feedback loop of the WPC system is relatively slow where it can take up to 90 ms to converge on a new rectifier voltage target. It should be understood that the instantaneous transient response of the system is open loop and dependent on the RX coil output impedance at that operating point. The “main loop” also determines if any conditions in [Table 8-3](#) are true in order to discontinue power transfer. See [Figure 8-3](#) which illustrates the active power transfer loop.

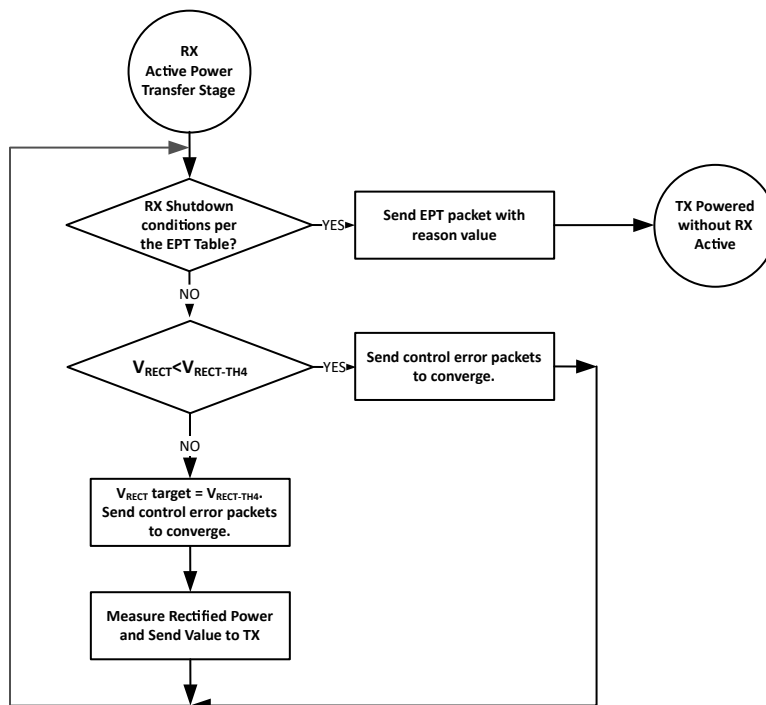


Figure 8-3. Active Power Transfer Flow Diagram

Another requirement of the WPC v1.3 specification is to send the measured received power. This task is enabled on the device by measuring the voltage on the FOD pin which is proportional to the output current and can be scaled based on the choice of the resistor to ground on the FOD pin.

8.3.2 R_{ILIM} Calculations

The BQ51013C includes a means of providing hardware overcurrent protection by means of an analog current regulation loop. The hardware current limit provides an extra level of safety by clamping the maximum allowable output current (current compliance). The calculation for the total R_{ILIM} resistance is as follows:

$$\begin{aligned}
 R_{ILIM} &= \frac{K_{IMAX}}{I_{MAX}} \\
 I_{ILIM} &= 1.2 \times I_{MAX} = \frac{K_{ILIM}}{R_{ILIM}} \\
 R_{ILIM} &= R_1 + R_{FOD}
 \end{aligned} \tag{1}$$

where

- I_{MAX} is the expected maximum output current during normal operation.
- I_{ILIM} is the hardware over current limit.

When referring to the application diagram shown in [Figure 9-1](#), R_{ILIM} is the sum of R_{FOD} and R_1 (the total resistance from the ILIM pin to GND).

8.3.3 Input Overvoltage

If the input voltage suddenly increases in potential (for example, due to a change in position of the equipment on the charging pad), the voltage-control loop inside the BQ51013C becomes active, and prevents the output from going beyond $V_{OUT-REG}$. The receiver then starts sending back error packets to the transmitter every 30 ms until the input voltage comes back to the $V_{RECT-REG}$ target, and then maintains the error communication every 250 ms.

If the input voltage increases in potential beyond $V_{RECT-OVP}$, the device switches off the LDO and communicates to the primary to bring the voltage back to $V_{RECT-REG}$. In addition, a proprietary voltage protection circuit is activated by means of C_{CLAMP1} and C_{CLAMP2} that protects the device from voltages beyond the maximum rating of the device.

8.3.4 Adapter Enable Functionality and EN1/EN2 Control

Figure 9-4 is an example application that shows the BQ51013C used as a wireless power receiver that can power multiplex between wired or wireless power for the down-system electronics. In the default operating mode, pins EN1 and EN2 are low, which activates the adapter enable functionality. In this mode, if an adapter is not present the AD pin will be low, and $\overline{AD-EN}$ pin will be pulled to the higher of the OUT and AD pins so that the PMOS between OUT and AD will be turned off. If an adapter is plugged in and the voltage at the AD pin goes above $V_{\overline{AD-EN}}$, then wireless charging is disabled and the $\overline{AD-EN}$ pin will be pulled approximately V_{AD} below the AD pin to connect AD to the secondary charger. The difference between AD and $\overline{AD-EN}$ is regulated to a maximum of $V_{AD-Diff}$ to ensure the V_{GS} of the external PMOS is protected.

The EN1 and EN2 pins include internal pulldown resistors (R_{PD}), so that if these pins are not connected BQ51013C defaults to $\overline{AD-EN}$ control mode. However, these pins can be pulled high to enable other operating modes. If the pins are pulled high or controlled by drivers and are subject to fast transient ($>10V/10ns$) higher than $\sim 8V$ it is recommended that current limit resistors (1k to 10k ohms) be added in series with the pins. See Table 8-1:

Table 8-1. Adapter Enable Functionality

EN1	EN2	RESULT
0	0	Adapter control enabled. If adapter is present then secondary charger is powered by adapter, otherwise wireless charging is enabled when wireless power is available. Communication current limit is enabled.
0	1	Disables communication current limit.
1	0	$\overline{AD-EN}$ is pulled low, whether or not adapter voltage is present. This feature can be used for USB OTG applications.
1	1	Adapter and wireless charging are disabled, power will not be delivered by the OUT pin in this mode.

Table 8-2. EN1/EN2 Control

EN1	EN2	WIRELESS POWER	WIRED POWER	OTG MODE	ADAPTIVE COMMUNICATION LIMIT	EPT
0	0	Enabled	Priority ⁽¹⁾	Disabled	Enabled	Not Sent to TX
0	1	Priority ⁽¹⁾	Enabled	Disabled	Disabled	Not Sent to TX
1	0	Disabled	Enabled	Enabled ⁽²⁾	N/A	EPT 0x00, Unknown
1	1	Disabled	Disabled	Disabled	N/A	EPT 0x01, Charge Complete

(1) If both wired and wireless power are present, wired or wireless is given priority based on EN2.

(2) Allows for a boost-back supply to be driven from the output terminal of the RX to the adapter port through the external back-to-back PMOS FET.

As described in Table 8-2, when EN1 is low, both wired and wireless power are useable. If both are present, priority is set between wired and wireless by EN2. When EN1 is high, wireless power is disabled and wired power functionality is set by EN2. When EN1 is high but EN2 is low, wired power is enabled if present. Additionally, USB OTG mode is active. In USB OTG mode, a charger connected to the OUT pin can power the AD pin. Note that EN1 must be pulled high from an active source (microcontroller). Finally, pulling both EN1 and EN2 high disables both wired and wireless charging.

Note

It is required to connect a back-to-back PMOS between AD and OUT so that voltage is blocked in both directions. Also, when AD mode is enabled no load can be pulled from the RECT pin as this could cause an internal device overvoltage in BQ51013C.

8.3.5 End Power Transfer Packet (WPC Header 0x02)

The WPC allows for a special command for the receiver to terminate power transfer from the transmitter termed End Power Transfer (EPT) packet. [Table 8-3](#) specifies the v1.3 MESSAGE column and their corresponding data field value. The condition column corresponds to the methodology used by BQ51013C to send equivalent message.

Table 8-3. End Power Transfer Packet

MESSAGE	VALUE	CONDITION
Unknown	0x00	$AD > V_{AD-Pres}$, or $\langle EN1\ EN2 \rangle = \langle 10 \rangle$, or $TS/CTRL > V_{CTRL-High}$, or $TS > V_{COLD}$
Charge Complete	0x01	$\langle EN1\ EN2 \rangle = \langle 11 \rangle$
Internal Fault	0x02	$T_J > 150^\circ\text{C}$ or $R_{ILIM} < 100\ \Omega$
Overtemperature	0x03	$TS < V_{HOT}$, or $TS/CTRL < V_{CTRL-Low}$
Overvoltage	0x04	V_{RECT} target does not converge
Overcurrent	0x05	Not sent
Battery Failure	0x06	Not sent
Reconfigure	0x07	Not sent
No Response	0x08	Not sent

8.3.6 Status Outputs

The BQ51013C has one status output, \overline{CHG} . This output is an open-drain NMOS device that is rated to 20 V. The open-drain FET connected to the \overline{CHG} pin will be turned on whenever the output of the power supply is enabled. The output of the power supply will not be enabled if the $V_{RECT-REG}$ does not converge at the no-load target voltage.

8.3.7 WPC Communication Scheme

The WPC communication uses a modulation technique termed “back-scatter modulation” where the receiver coil is dynamically loaded in order to provide amplitude modulation of the transmitter's coil voltage and current. This scheme is possible due to the fundamental behavior between two loosely coupled inductors (here between the TX and RX coils). This type of modulation can be accomplished by switching in and out a resistor at the output of the rectifier, or by switching in and out a capacitor across the AC1/AC2 net. [Figure 8-4](#) shows how to implement resistive modulation.

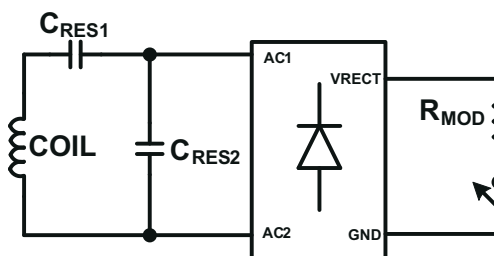


Figure 8-4. Resistive Modulation

[Figure 8-5](#) shows how to implement capacitive modulation.

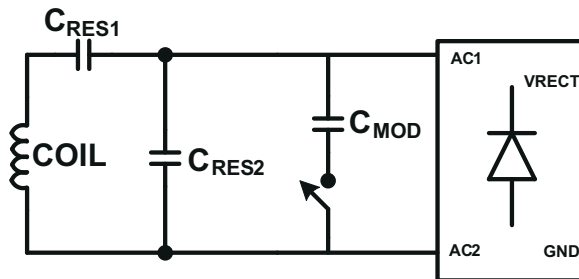


Figure 8-5. Capacitive Modulation

The amplitude change in the TX coil voltage or current can be detected by the transmitter's decoder. The resulting signal observed by the TX is shown in Figure 8-6.

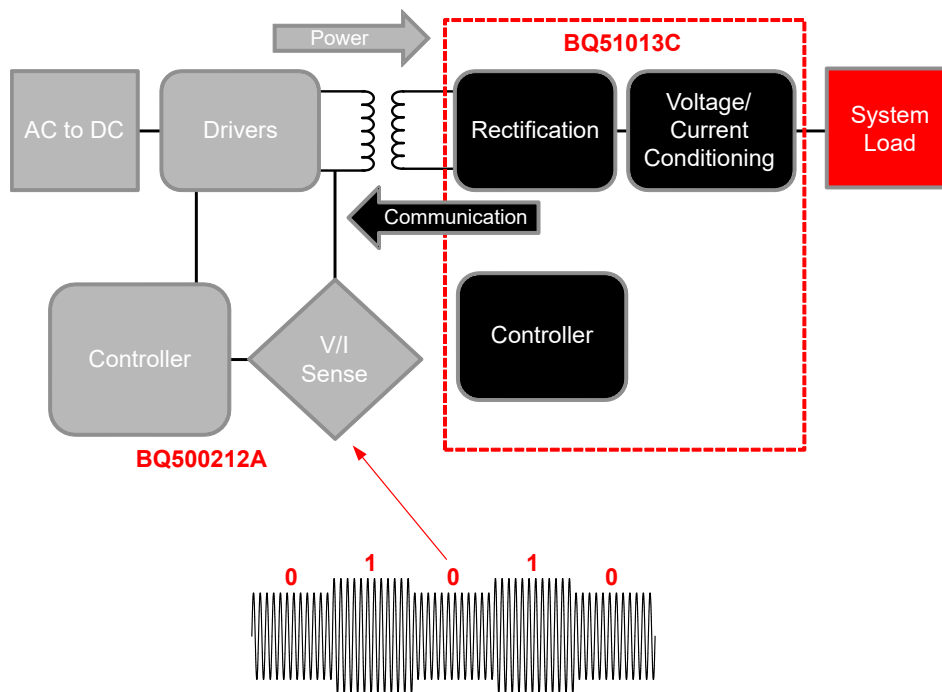


Figure 8-6. TX Coil Voltage/Current

The WPC protocol uses a differential bi-phase encoding scheme to modulate the data bits onto the TX coil voltage/current. Each data bit is aligned at a full period of 0.5 ms (t_{CLK}) or 2 kHz. An encoded ONE results in two transitions during the bit period and an encoded ZERO results in a single transition. See Figure 8-7 for an example of the differential bi-phase encoding.

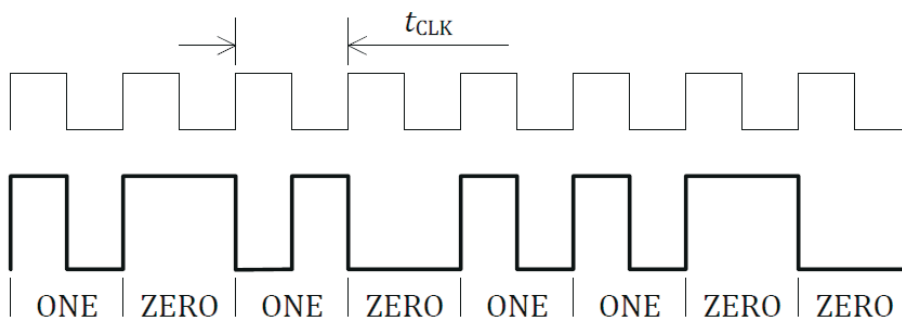


Figure 8-7. Differential Bi-Phase Encoding Scheme (WPC Volume 1: Low Power, Part 1 Interface Definition)

The bits are sent LSB first and use an 11-bit asynchronous serial format for each portion of the packet. This includes one start bit, n-data bytes, a parity bit, and a single stop bit. The start bit is always ZERO and the parity bit is odd. The stop bit is always ONE. Figure 8-8 shows the details of the asynchronous serial format.

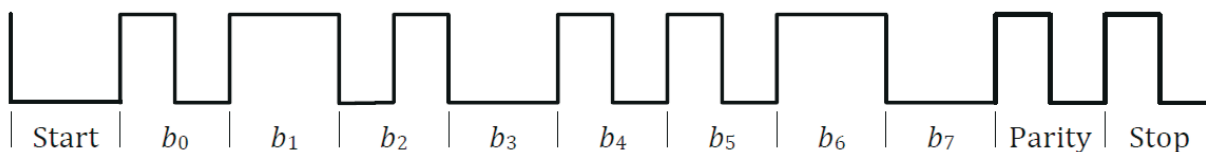


Figure 8-8. Asynchronous Serial Formatting (WPC Volume 1: Low Power, Part 1 Interface Definition)

Each packet format is organized as shown in Figure 8-9.



Figure 8-9. Packet Format (WPC Volume 1: Low Power, Part 1 Interface Definition)

Figure 7-17 shows an example waveform of the receiver sending a rectified power packet (header 0x04).

8.3.8 Communication Modulator

The BQ51013C device provides two identical, integrated communication FETs which are connected to the pins COMM1 and COMM2. These FETs are used for modulating the secondary load current which allows the BQ51013C to communicate error control and configuration information to the transmitter. Figure 8-10 shows how the COMMx pins can be used for resistive load modulation. Each COMMx pin can handle at most a 24- Ω communication resistor. Therefore, if a COMMx resistor between 12 Ω and 24 Ω is required, COMM1 and COMM2 pins must be connected in parallel. The BQ51013C device does not support a COMMx resistor less than 12 Ω .

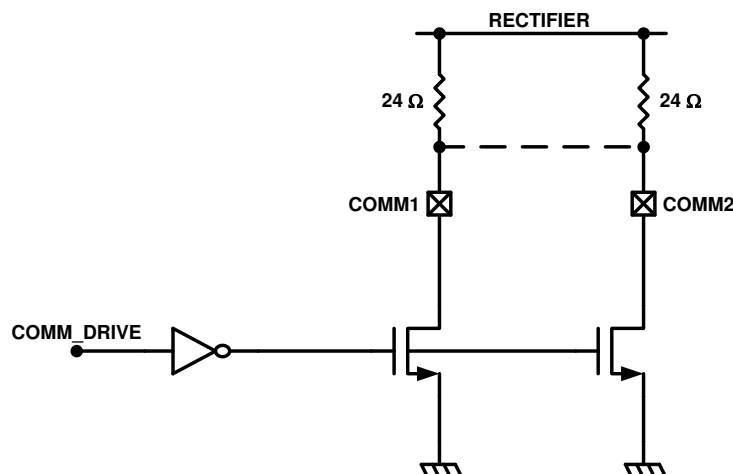


Figure 8-10. Resistive Load Modulation

In addition to resistive load modulation, the BQ51013C is also capable of capacitive load modulation as shown in Figure 8-11. In this case, a capacitor is connected from COMM1 to AC1 and from COMM2 to AC2. When the COMMx switches are closed there is effectively a 22 nF capacitor connected between AC1 and AC2. Connecting a capacitor in between AC1 and AC2 modulates the impedance seen by the coil, which will be reflected in the primary as a change in current.

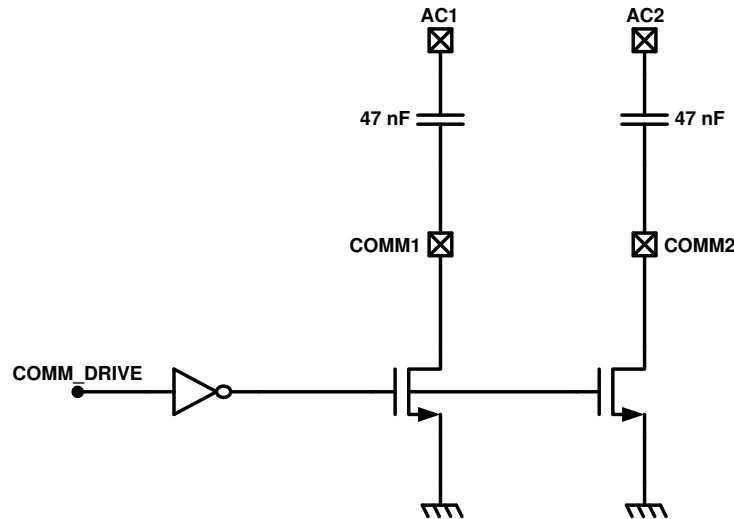


Figure 8-11. Capacitive Load Modulation

8.3.9 Adaptive Communication Limit

The Qi communication channel is established through backscatter modulation as described in the previous sections. This type of modulation takes advantage of the loosely coupled inductor relationship between the RX and TX coils. Essentially, the switching in-and-out of the communication capacitor or resistor adds a transient load to the RX coil in order to modulate the TX coil voltage and current waveform (amplitude modulation). The consequence of this technique is that a load transient (load current noise) from the mobile device has the same signature. To provide noise immunity to the communication channel, the output load transients must be isolated from the RX coil. The proprietary feature *Adaptive Communication Limit* achieves this by dynamically adjusting the current limit of the regulator. When the regulator is put in current limit, any load transients will be offloaded to the battery in the system.

Note that this requires the battery charger device to have input voltage regulation (weak adapter mode). The output of the RX appears as a weak supply if a transient occurs above the current limit of the regulator.

The Adaptive Communication Limit feature has two current limit modes and is detailed in [Table 8-4](#).

Table 8-4. Adaptive Communication Limit

I_{OUT}	COMMUNICATION CURRENT LIMIT
< 300 mA	Fixed 400 mA
> 300 mA	$I_{OUT} + 50$ mA

The first mode is illustrated in [Figure 7-15](#). In this plot, an output load pulse of 300 mA is periodically introduced on a DC current level of 200 mA. Therefore, the 400 mA current limit is enabled. The pulses on V_{RECT} indicate that a communication packet event is occurring. When the output load pulse occurs, the regulator limits the pulse to a constant 400 mA and, therefore, preserves communication. Note that V_{OUT} drops to 4.5 V instead of GND. A charger device with an input voltage regulation set to 4.5 V allows this to occur by offloading the load transient support to the mobile device's battery.

The second mode is illustrated in [Figure 7-16](#). In this plot, an output pulse of 200 mA is periodically introduced on a DC current level of 400 mA. Therefore, the tracking current mode ($I_{OUT} + 50$ mA) is enabled. In this mode, the BQ51013C measures the active output current and sets the regulator's current limit 50 mA above this measurement. When the load pulse occurs during a communication packet event, the output current is regulated to 450 mA. As the communication packet event has finished the output load is allowed to increase. Note that during the time the regulator is in current limit V_{OUT} is reduced to 4.5 V and 5 V when not in current limit.

8.3.10 Synchronous Rectification

The BQ51013C provides an integrated, self-driven synchronous rectifier that enables high-efficiency AC to DC power conversion. The rectifier consists of an all NMOS H-Bridge driver where the backgates of the diodes are configured to be the rectifier when the synchronous rectifier is disabled. During the initial start-up of the WPC system the synchronous rectifier is not enabled. At this operating point, the DC rectifier voltage is provided by the diode rectifier. Once V_{RECT} is greater than V_{UVLO} , half synchronous mode will be enabled until the load current surpasses I_{BAT-SR} . Above I_{BAT-SR} the full synchronous rectifier stays enabled until the load current drops back below the hysteresis level ($I_{BAT-SRH}$) where half-synchronous mode is enabled re-enabled.

8.3.11 Temperature Sense Resistor Network (TS)

The BQ51013C includes a ratiometric external temperature sense function. The temperature sense function has two ratiometric thresholds which represent a hot and cold condition. An external temperature sensor is recommended in order to provide safe operating conditions for the receiver product. This pin is best used for monitoring the surface that can be exposed to the end user (place the NTC resistor closest to where the user would physically contact the end product).

Figure 8-12 allows for any NTC resistor to be used with the given V_{HOT} and V_{COLD} thresholds.

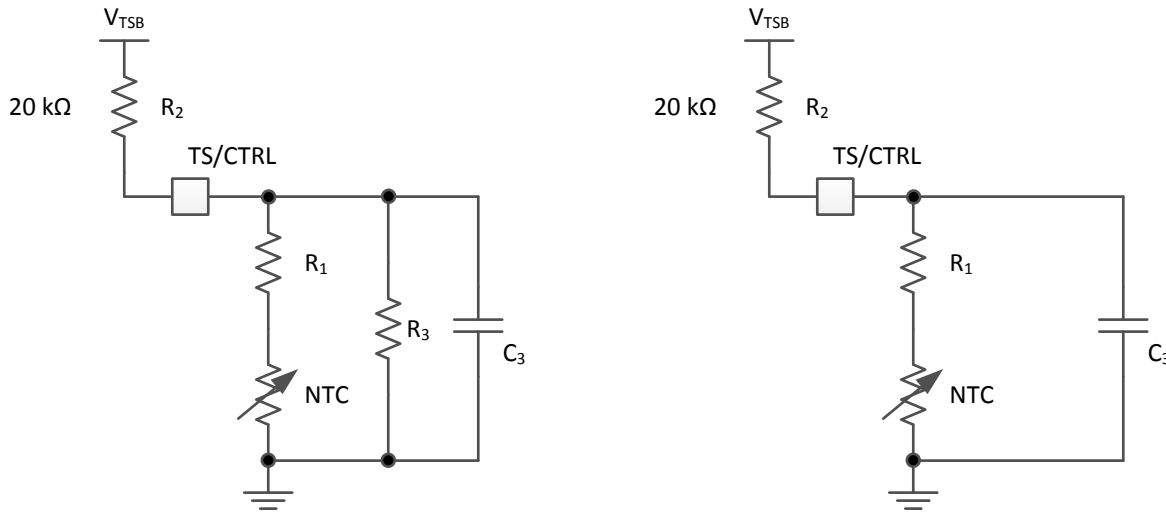


Figure 8-12. NTC Circuit Options For Safe Operation of the Wireless Receiver Power Supply

The resistors R_1 and R_3 can be solved by resolving the system of equations at the desired temperature thresholds. The two equations are:

$$\begin{aligned} \%V_{COLD} &= \frac{\left(\frac{R_3 (R_{NTC|TCOLD} + R_1)}{R_3 + (R_{NTC|TCOLD} + R_1)} \right)}{\left(\frac{R_3 (R_{NTC|TCOLD} + R_1)}{R_3 + (R_{NTC|TCOLD} + R_1)} \right) + R_2} \times 100 \\ \%V_{HOT} &= \frac{\left(\frac{R_3 (R_{NTC|THOT} + R_1)}{R_3 + (R_{NTC|THOT} + R_1)} \right)}{\left(\frac{R_3 (R_{NTC|THOT} + R_1)}{R_3 + (R_{NTC|THOT} + R_1)} \right) + R_2} \times 100 \end{aligned} \quad (2)$$

Where:

$$R_{NTC|T_{COLD}} = R_O e^{\beta \left(\frac{1}{T_{COLD}} - \frac{1}{T_O} \right)}$$

$$R_{NTC|T_{HOT}} = R_O e^{\beta \left(\frac{1}{T_{HOT}} - \frac{1}{T_O} \right)}$$
(3)

where

- T_{COLD} and T_{HOT} are the desired temperature thresholds in degrees Kelvin.
- R_O is the nominal resistance.
- β is the temperature coefficient of the NTC resistor.

R_2 is fixed at 20 k Ω . An example solution is provided:

- $R_1 = 4.23$ k Ω
- $R_3 = 66.8$ k Ω

where the chosen parameters are:

- $\%V_{HOT} = 19.6\%$
- $\%V_{COLD} = 58.7\%$
- $T_{COLD} = -10^\circ\text{C}$
- $T_{HOT} = 100^\circ\text{C}$
- $\beta = 3380$
- $R_O = 10$ k Ω

The plot of the percent V_{TSB} vs. temperature is shown in [Figure 8-13](#):

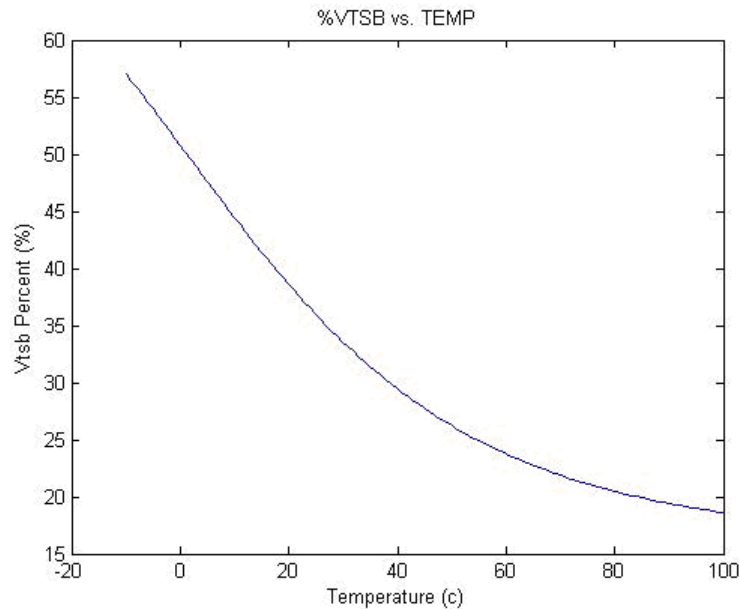


Figure 8-13. Example Solution for an NTC Resistor with $R_O = 10$ k Ω and $\beta = 3380$

[Figure 8-14](#) illustrates the periodic biasing scheme used for measuring the TS state. An internal TS_READ signal enables the TS bias voltage ($V_{TS-Bias}$) for 24 ms. During this period, the TS comparators are read (with t_{TS} deglitch) and appropriate action is taken based on the temperature measurement. After this 24-ms period has elapsed, the TS_READ signal goes low, which causes the TS/CTRL pin to become high impedance. During the next 35 ms (priority packet period) or 235 ms (standard packet period), the TS voltage is monitored and compared to $V_{CTRL-HI}$. If the TS voltage is greater than $V_{CTRL-HI}$ then a secondary device is driving the TS/CTRL pin and a CTRL = '1' is detected.

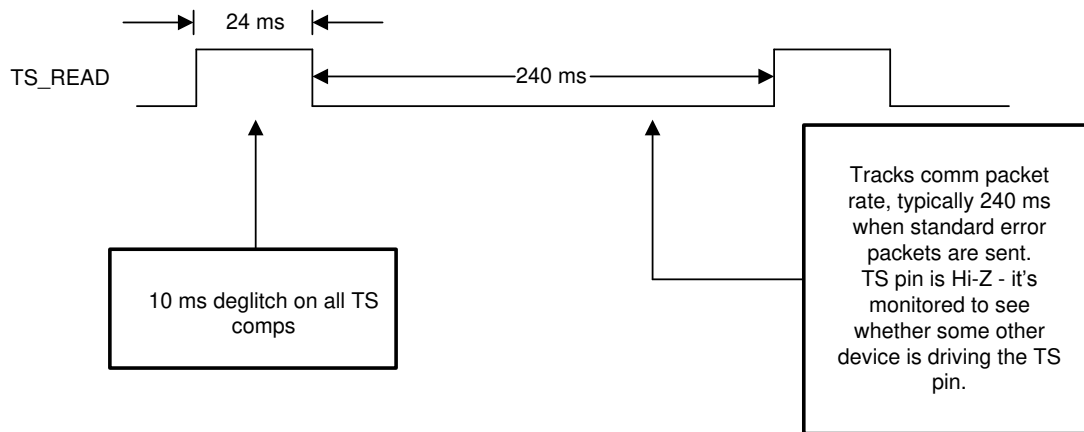


Figure 8-14. Timing Diagram For TS Detection Circuit

8.3.12 3-State Driver Recommendations for the TS/CTRL Pin

The TS/CTRL pin offers three functions with one 3-state driver interface:

- NTC temperature monitoring
- Over-Temperature Fault
- End Power Transfer 0x00 (EPT Unknown)

A 3-state driver can be implemented with the circuit in [Figure 8-15](#) and the use of two GPIO connections. M3 and M4 and both resistors are external components.

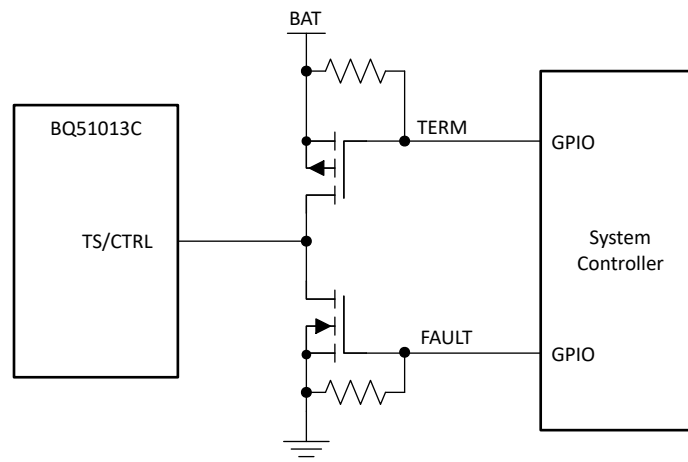


Figure 8-15. 3-State Driver For TS/CTRL

Note that the signals *TERM* and *FAULT* are given by two GPIOs. The truth table for this circuit is found in [Table 8-5](#):

Table 8-5. Truth Table

TERM	FAULT	F (Result)
1	0	High Impedance (Normal Mode)
0	0	End Power Transfer 0x00
1	1	End Power Transfer 0x03

The default setting is TERM / FAULT = 1 / 0. In this condition, the TS-CTRL net is high impedance (high-z) and the NTC function is allowed to operate, normal operation. When TERM / FAULT = 1 / 1 the TS-CTRL pin is pulled to GND and the RX is shutdown with End Power Transfer Over Temperature sent to TX. When TERM / FAULT =

0 / 0, the TS-CTRL pin is pulled to the battery and the RX is shutdown with End Power Transfer Unknown sent to the TX.

8.3.13 Thermal Protection

The BQ51013C includes a thermal shutdown protection. If the die temperature reaches T_{J-SD} , the LDO is shut off to prevent any further power dissipation. In this case BQ51013C will send an EPT message of internal fault (0x02). Once the temperature falls T_{J-Hys} below T_{J-SD} , operation can continue.

8.3.14 WPC v1.3 Compliance – Foreign Object Detection

In order to enable a Power Transmitter to monitor the power loss across the interface as one of the possible methods to limit the temperature rise of Foreign Objects, the BQ51013C reports its Received Power to the Power Transmitter. The Received Power equals the power that is available from the output of the Power Receiver plus any power that is lost in producing that output power (the power loss in the Secondary Coil and series resonant capacitor, the power loss in the Shielding of the Power Receiver, the power loss in the rectifier). This means the BQ51013C will send received power information with known accuracy to the transmitter.

To receive WPC Certification the Device Under Test (DUT) is tested on a Reference Transmitter whose transmitted power is calibrated, the receiver must send a received power such that:

$$0 > (TX\ PWR)_{REF} - (RX\ PWR\ out)_{DUT} > -375\ mW \quad (4)$$

This 375-mW bias ensures that system will remain interoperable.

WPC Transmitter is tested to see if it can detect reference Foreign Objects with a Reference receiver.

8.4 Device Functional Modes

The operational modes of the BQ51013C are described in the [Section 8.3](#). The BQ51013C has several functional modes. Start-up refers to the initial power transfer and communication between the receiver (BQ51013C circuit) and the transmitter. Power transfer refers to any time that the TX and RX are communicating and power is being delivered from the TX to the RX. Power transfer termination occurs when the RX is removed from the TX, power is removed from the TX, or the RX requests power transfer termination.

9 Application and Implementation

Note

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes, as well as validating and testing their design implementation to confirm system functionality.

9.1 Application Information

The BQ51013C is a fully integrated wireless power receiver in a single device. The device complies with the WPC v1.3 specifications for a wireless power receiver. When paired with a WPC v1.3 compliant transmitter, it can provide up to 5 W of power. There are several tools available for the design of the system. These tools may be obtained by checking the product page at www.ti.com/product.

9.2 Typical Applications

9.2.1 BQ51013C Wireless Power Receiver Used as a Power Supply

The following application discussion covers the requirements for setting up the BQ51013C in a Qi-compliant system for use as a power supply.

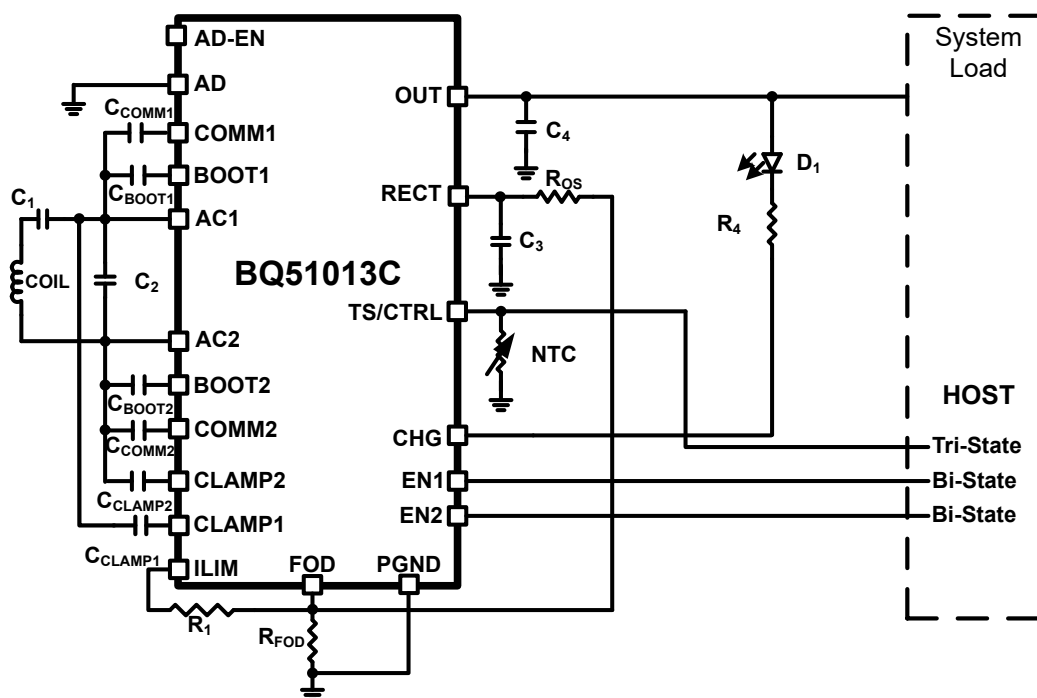


Figure 9-1. BQ51013C Used as a Wireless Power Receiver and Power Supply for System Loads

9.2.1.1 Design Requirements

This application is for a system that has varying loads from less than 100 mA up to 1 A. It must work with any Qi-certified transmitter. There is no requirement for any external thermal measurements. An LED indication is required to indicate an active power supply. Each of the components from the application drawing will be examined.

9.2.1.2 Detailed Design Procedure

9.2.1.2.1 Using the BQ51013C as a Wireless Power Supply: (See Figure 9-1)

Figure 9-4 is the schematic of a system which uses the BQ51013C as a power supply while power multiplexing the wired (adapter) port.

When the system shown in Figure 9-1 is placed on the charging pad, the receiver coil is inductively coupled to the magnetic flux generated by the coil in the charging pad which consequently induces a voltage in the receiver coil. The internal synchronous rectifier feeds this voltage to the RECT pin which has the filter capacitor C3.

The BQ51013C identifies and authenticates itself to the primary using the COMM pins by switching on and off the COMM FETs and hence switching in and out C_{COMM} . If the authentication is successful, the transmitter will remain powered on. The BQ51013C measures the voltage at the RECT pin, calculates the difference between the actual voltage and the desired voltage $V_{RECT-REG}$, and sends back error packets to the primary.

During power up, the LDO is held off until the $V_{RECT-REG}$ threshold converges. The voltage control loop ensures that the output voltage is maintained at $V_{OUT-REG}$ to power the system. The BQ51013C meanwhile continues to monitor the input voltage, and maintains sending error packets to the primary every 250 ms. If a large overshoot occurs, the feedback to the primary speeds up to every 32 ms in order to converge on an operating point in less time.

9.2.1.2.2 Series and Parallel Resonant Capacitor Selection

Shown in Figure 9-1, the capacitors C1 (series) and C2 (parallel) make up the dual resonant circuit with the receiver coil. These two capacitors must be sized correctly per the WPC v1.3 specification. Figure 9-2 illustrates the equivalent circuit of the dual resonant circuit:

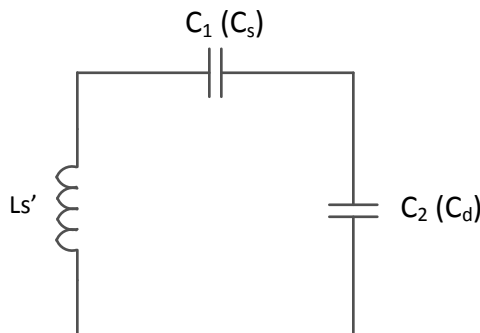


Figure 9-2. Dual Resonant Circuit With the Receiver Coil

The Power Receiver Design Requirements in Volume 1 of the WPC v1.3 specification highlights in detail the sizing requirements. To summarize, the receiver designer will be required to take inductance measurements with a standard test fixture as shown in Figure 9-3:

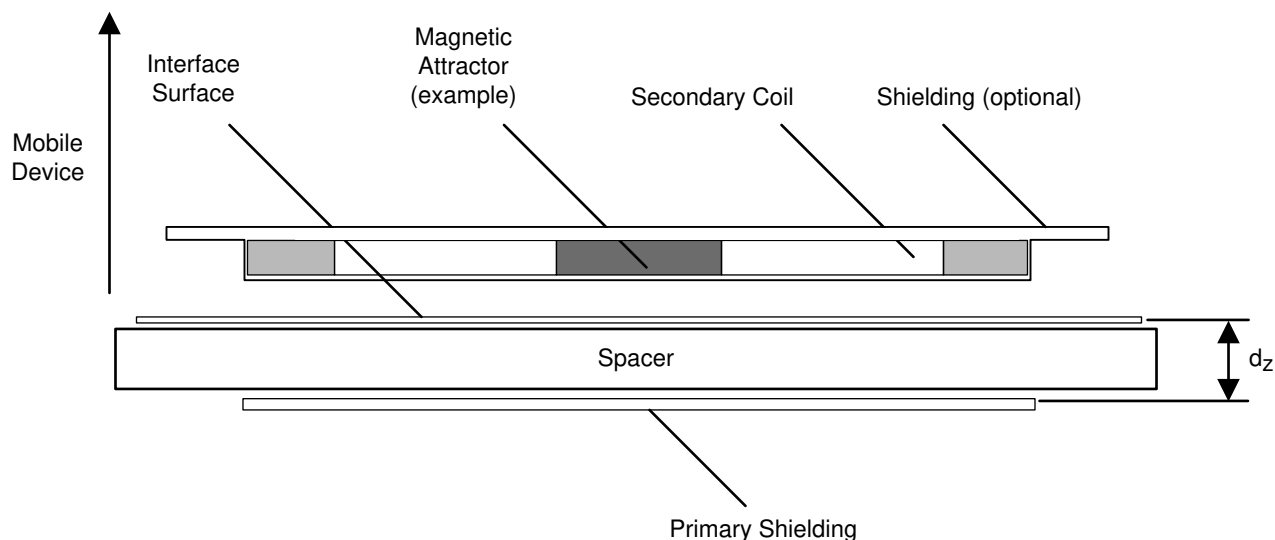


Figure 9-3. WPC v1.3 Receiver Coil Test Fixture For the Inductance Measurement L_s' (Copied From System Description Wireless Power Transfer, Volume 1: Low Power, Part 1 Interface Definition, Version 1.1)

The primary shield is to be 50 mm × 50 mm × 1 mm of Ferrite material PC44 from TDK Corp. The gap d_z is to be 3.4 mm. The receiver coil, as it will be placed in the final system (for example, the back cover and battery must be included if the system calls for this), is to be placed on top of this surface and the inductance is to be measured at 1-V RMS and a frequency of 100 kHz. This measurement is termed L_s' . The same measurement is to be repeated without the test fixture shown in Figure 9-3. This measurement is termed L_s or the free-space inductance. Each capacitor can then be calculated using Equation 5:

$$C_1 = \left[(f_S \times 2\pi)^2 \times L'_S \right]^{-1}$$

$$C_2 = \left[(f_D \times 2\pi)^2 \times L_S - \frac{1}{C_1} \right]^{-1} \quad (5)$$

where

- f_S is 100 kHz +5/-10%.
- f_D is 1 MHz ±10%.

C_1 must be chosen first prior to calculating C_2 .

The quality factor must be greater than 77 and can be determined by Equation 6:

$$Q = \frac{2\pi \cdot f_D \cdot L_S}{R} \quad (6)$$

where

- R is the DC resistance of the receiver coil.

All other constants are defined above.

For this application, the selected coil inductance, L_s , is 11 μ H and the L_s' is 16 μ H with a DC resistance of 191 m Ω . Using Equation 5, the C_1 resolves to 158.3 nF (with a range of 144 nF to 175 nF). For an optimum solution

of 3 capacitors in parallel, the chosen capacitors are 68 nF, 47 nF, and 39 nF for a total of 154 nF, well within the desired range. Using the same equation (and the chosen value for C_1), C_2 resolves to 2.3 nF. This is easily met with capacitors of 2.2 nF and 100 pF. The C_1 and C_2 capacitors must have a minimum voltage rating of 25 V. Solving for the quality factor (Q in Equation 6), gives a value of over 500.

Table 9-1 lists the recommended RX coils.

9.2.1.2.3 Recommended RX Coils

Table 9-1. Recommended RX Coils

MANUFACTURER	PART NUMBER	DIMENSIONS	Ls	OUTPUT CURRENT RANGE	APPLICATION
Würth Electronics	760308103215	48 mm × 32 mm	14.3μH	50 mA - 1000 mA	General 5-V Power Supply
XFMRS	XFMCC483201-143	48 mm × 32 mm	14.3 μH	50 mA - 1000 mA	General 5-V Power Supply
TDK	WR483265-15F5-G	48 mm × 32 mm	13.3μH	50 mA - 1000 mA	General 5-V Power Supply
TDK	WR222230-26M8-G	22 mm round	27μH	50 mA - 500 mA	General 5-V Power Supply

9.2.1.2.4 COMM, CLAMP, and BOOT Capacitors

For most applications, the COMM, CLAMP, and BOOT capacitance values will be chosen to match the BQ51013CEVM-764.

The BOOT capacitors are used to allow the internal rectifier FETs to turn on and off properly. These capacitors are from AC1 to BOOT1 and from AC2 to BOOT2 and must have a minimum 25-V rating. A 10-nF capacitor with a 25-V rating is chosen.

The CLAMP capacitors are used to aid in the clamping process to protect against overvoltage. These capacitors are from AC1 to CLAMP1 and from AC2 to CLAMP2 and must have a minimum 25-V rating. A 0.47-μF capacitor with a 25-V rating is chosen.

The COMM capacitors are used to facilitate the communication from the RX to the TX. This selection can vary a bit more than the BOOT and CLAMP capacitors. In general, a 22-nF capacitor is recommended. Based on the results of testing of the communication robustness in the final solution, a change to a 47-nF capacitor may be in order. The larger the capacitor the larger the deviation will be on the coil which sends a stronger signal to the TX. This also decreases the efficiency somewhat. In this case, a 22-nF capacitor with a 25-V rating is chosen.

9.2.1.2.5 Control Pins and \overline{CHG}

This section discusses the pins that control the functions of the BQ51013C (AD, $\overline{AD_EN}$, EN1, EN2, and TS/CTRL).

This solution uses wireless power exclusively. The AD pin is tied low to disable wired power interaction. The output pin $\overline{AD_EN}$ is left floating.

EN1 and EN2 are tied to the system controller GPIO pins. This allows the system to control the wireless power transfer. Normal operation leaves EN1 and EN2 low or floating (GPIO low or high impedance). EN1 and EN2 have internal pulldown resistors. With both EN1 and EN2 low, wireless power is enabled and power can be transferred whenever the RX is on a suitable TX. The RX system controller can terminate power transfer and send an EPT 0x01 (Charge Complete) by setting EN1=EN2=1. The TX will terminate power when the EPT 0x01 is received. The TX will continue to test for power transfer, but will not engage until the RX requests power. For example, if the TX is the BQ500212A, the TX will send digital pings approximately once per 5 seconds. During each ping, the BQ51013C will resend the EPT 0x01. Between the pings, the BQ500212A goes into low power "Sleep" mode reducing power consumption. When the RX system controller determines it is time to resume power transfer (for example, the battery voltage is below its recharge threshold) the controller simply returns EN1 and EN2 to low (or float) states. The next ping of the BQ500212A will power the BQ51013C which will now communicate that it is time to transfer power. The TX and RX communication resumes and power transfer is reinitiated.

The TS/CTRL pin will be used as a temperature sensor (with the NTC) and maintain the ability to terminate power transfer through the system controller. In this case, the GPIO will be in high impedance for normal NTC (Temperature Sense) control.

The $\overline{\text{CHG}}$ pin is used to indicate power transfer. A 2.1V forward bias LED is used for D_1 with a current limiting 1.5k Ω series resistor. The LED and resistor are tied from OUT to PGND and D_1 will light during power transfer.

9.2.1.2.6 Current Limit and FOD

The current limit and foreign object detection functions are related. The current limit is set by $R_1 + R_{\text{FOD}}$. R_{FOD} and R_{os} are determined by FOD calibration. Default values of 20 k Ω for R_{os} and 196 Ω for R_{FOD} are used. The final values need to be determined based on the FOD calibration. The tool for FOD calibration can be found on the BQ51013C web folder under "Tools & software". Good practice is to set the layout with 2 resistors for R_{os} and 2 for R_{FOD} to allow for precise values once the calibration is complete.

After setting R_{FOD} , R_1 can be calculated based on the desired current limit. The maximum current for this solution under normal operating conditions (I_{MAX}) is 1 A. Using Equation 1 to calculate the maximum current yields a value of 262 Ω for R_{ILIM} . With R_{FOD} set to 196 Ω the remaining resistance for R_1 is 66 Ω . This also sets the hardware current limit to 1.2 A to allow for temporary current surges without system performance concerns.

9.2.1.2.7 RECT and OUT Capacitance

RECT capacitance is used to smooth the AC to DC conversion and to prevent minor current transients from passing to OUT. For this 1-A I_{MAX} , select two 10- μF capacitors and one 0.1- μF capacitor. These should be rated to 16 V.

OUT capacitance is used to reduce any ripple from minor load transients. For this solution, a single 10- μF capacitor and a single 0.1- μF capacitor are used.

9.2.2 Dual Power Path: Wireless Power and DC Input

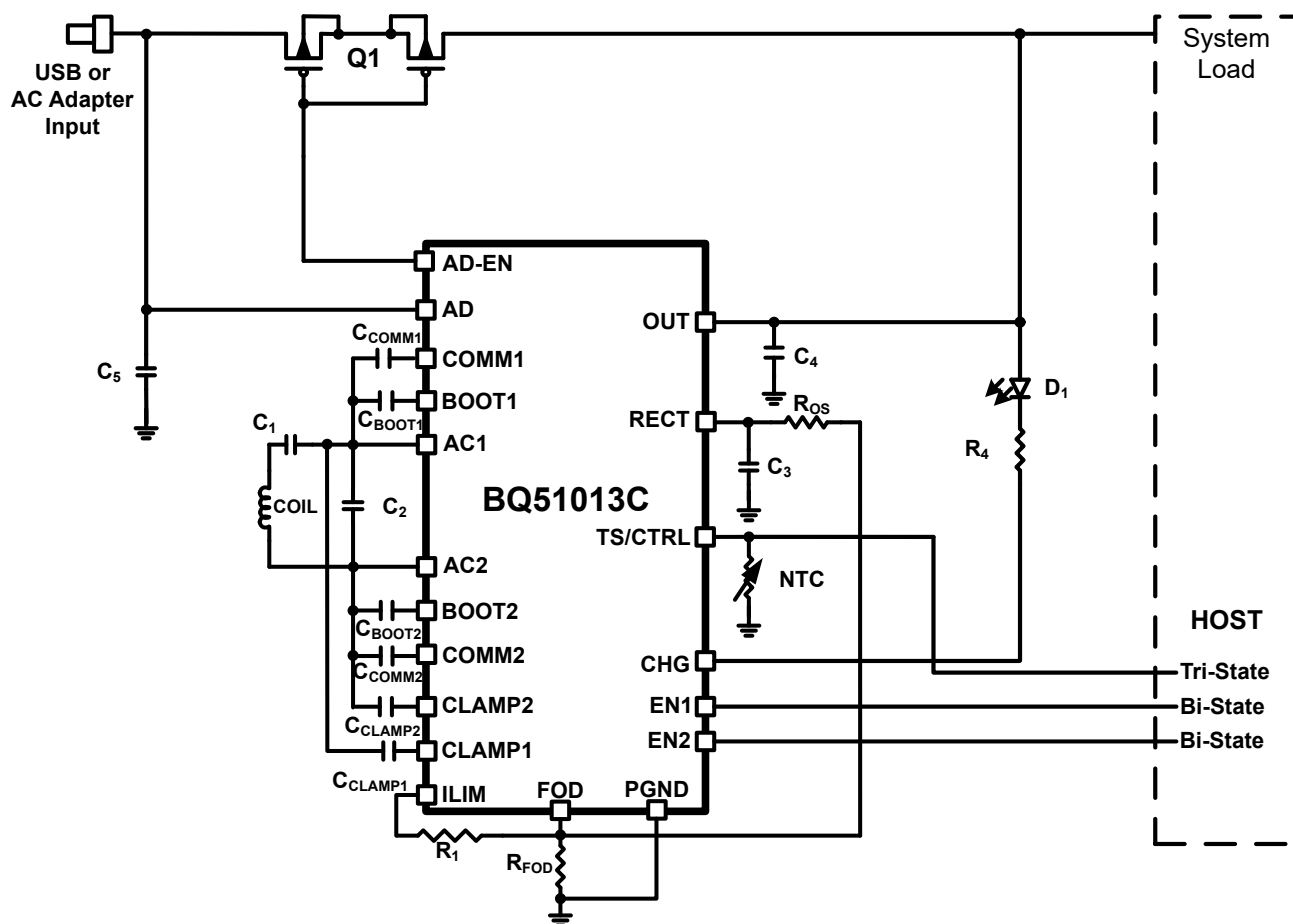


Figure 9-4. BQ51013C Used as a Wireless Power Receiver and Power Supply for System Loads With Adapter Power-Path Multiplexing

9.2.2.1 Design Requirements

This solution adds the ability to disable wireless charging with the AD and $\overline{\text{AD_EN}}$ pins. A DC supply (USB or AC Adapter with DC output) can also be used to power the subsystem. This can occur during wireless power transfer or without wireless power transfer. The system must allow power transfer without any back-flow or damage to the circuitry.

9.2.2.2 Detailed Design Procedure

The components chosen for the [Section 9.2.1](#) system are identical. Adding a blocking FET while using the BQ51013C for control is the only addition to the circuitry. The AD pin will be tied to the DC input as a threshold detector. The $\overline{\text{AD_EN}}$ pin will be used to enable or disable the blocking FET. The blocking FET must be chosen to handle the appropriate current level and the DC voltage level supplied from the input. In this example, the expectation is that the DC input will be 5 V with a maximum current of 1 A (same configuration as the wireless power supply). The CSD75207W15 is a good fit because it is a P-Channel, -20-V , 3.9-A FET pair in a 1.5-mm² WCSP.

The following scope plots show behavior under different conditions.

[Figure 9-5](#) shows the transition from wireless power to wired power when power is added to the AD pin. V_{RECT} drops and there is a short time (I_{OUT} drops to zero) when neither source is providing power. When Q1 is enabled (through $\overline{\text{AD_EN}}$) the output current turns back on. Note the RECT voltage after about 500 ms. This is the TX sending a ping to check to see if power is required. RECT returns to low after the BQ51013C informs the TX it does not need power (without enabling the OUT pin). This timing is based on the TX (BQ500212A used here).

[Figure 9-6](#) shows the transition to wireless power when the AD voltage is removed. Note that after wired power is removed, the next ping from the (BQ500212A) will energize the BQ51013C. Once the rectifier voltage is stable the output will turn on.

[Figure 9-7](#) shows a system placed onto the transmitter with AD already powered. The TX sends a ping which the RX responds to and informs the TX that no power is needed. The ping will continue with the timing based on the TX used.

[Figure 9-8](#) shows the AD added when the RX is not on a TX. This indicates normal start-up without requirement of the TX.

9.2.2.3 Application Curves

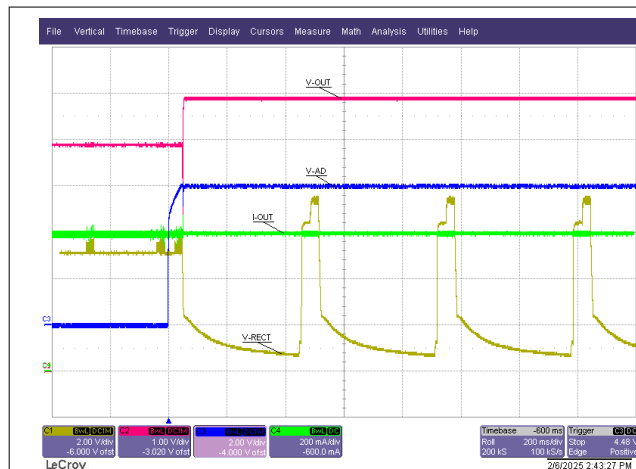
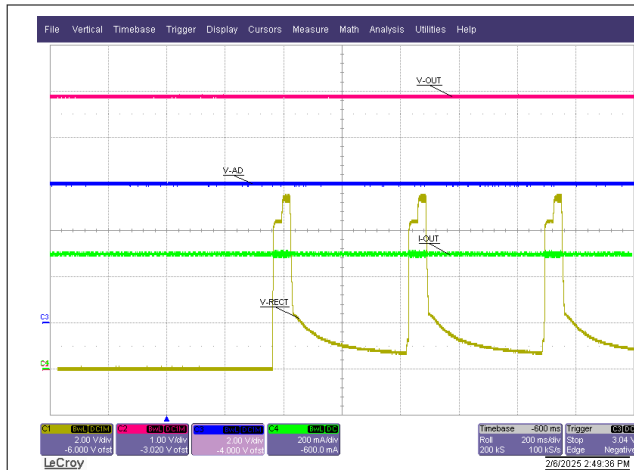


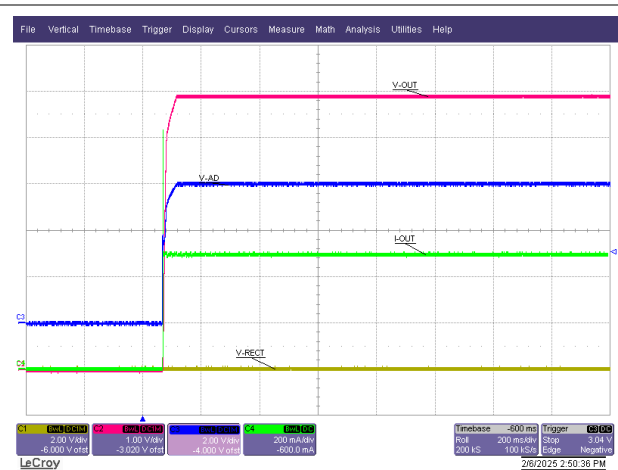
Figure 9-5. Transition Between Wireless Power and Wired Power (EN1 = EN2 = LOW)



Figure 9-6. Transition Between Wired Power and Wireless Power (EN1 = EN2 = LOW)



**Figure 9-7. Wireless Power Start-Up With $V_{AD} = 5\text{ V}$
(EN1 = EN2 = LOW)**



**Figure 9-8. AD Power Start-Up With No Transmitter
(EN1 = EN2 = LOW)**

9.2.3 Wireless and Direct Charging of a Li-Ion Battery at 400 mA

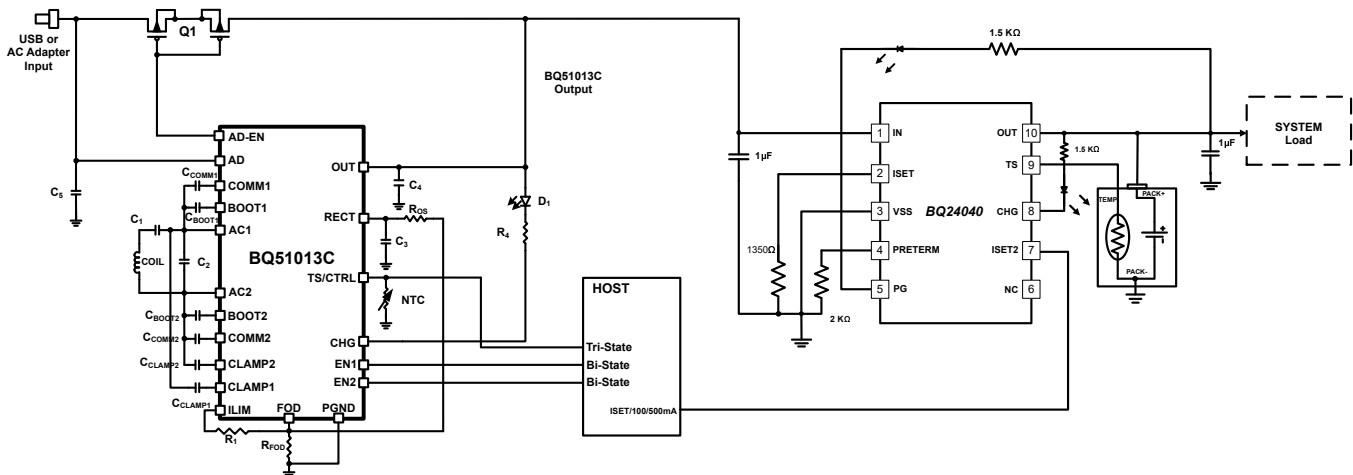


Figure 9-9. BQ51013C Used as a Wireless Power Supply With Adapter Multiplexing for a Linear Charger

9.2.3.1 Design Requirements

The goal of this design is to charge a 3.7 V Li-Ion battery at 400mA either wirelessly or with a direct USB wired input. This design will use the BQ51013C wireless power supply and the BQ24040 single-cell Li-Ion battery charger. A low resistance path has to be created between the output of BQ51013C and the input of BQ24040.

9.2.3.2 Detailed Design Procedure

The basic BQ51013C design is identical to the [Section 9.2.2](#). The BQ51013C OUT pin is tied to the output of Q1 and directly to the IN pin of the BQ24040. No other changes to the BQ51013C circuitry are required.

The BQ24040 has a few parameters that need to be programmed for this charger to work properly. Ceramic decoupling capacitors are needed on the IN and OUT pins using the values shown in [Figure 9-9](#). After evaluation during actual system operational conditions, the final values may be adjusted up or down. In high amplitude pulsed load applications, the IN and OUT capacitors will generally require larger values. The next step is setting up the fast charge current and pre-charge and termination current.

Program the Fast Charge Current, ISET: $R_{ISET} = [K_{ISET}/I_{OUT}] = [540 \text{ A}\Omega / 0.4 \text{ A}] = 1.350 \Omega$.

Program the Termination Current, ITERM: $R_{\text{PRE-TERM}} = [K_{\text{TERM}}/\% \text{OUT-FC}] = 200 \, \Omega/\% \times 10\% = 2 \, \text{k}\Omega$.

TS Function: To enable the temperature sense function, a 10-k Ω NTC thermistor (103AT) from TS to VSS should be placed in the battery pack. To disable the temperature sense function, use a fixed 10-k Ω resistor between TS and VSS.

Figure 9-10 shows start-up of the wireless system with the BQ24040 charger when TX power is applied after the full RX system has been placed on the charging pad. Channel 1 (yellow) shows RECT pin voltage of the BQ51013C starting up. The 5V output from BQ51013C is seen on Channel 2 (Red). The output of the BQ24040 is shown on Channel 3 (blue). Battery current can be seen on Channel 4 (green).

Figure 9-11 shows a similar condition but in this case, the battery is not connected initially, so the battery detection routine can be observed. After the battery is connected to the charger, the charge increases to 400mA. Battery current can be seen on Channel 4 (green).

9.2.3.3 Application Curves

The following plots show the performance of the BQ51013C + charger solution.

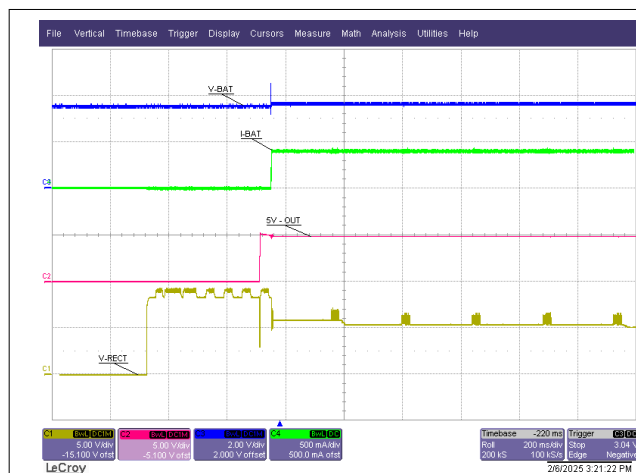


Figure 9-10. System Start-Up

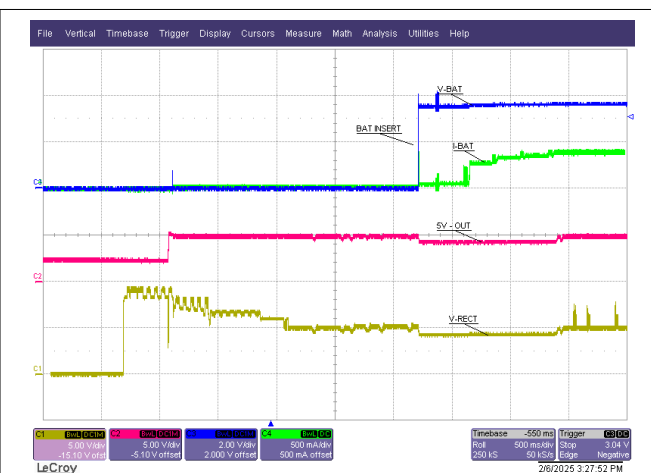


Figure 9-11. System Start-Up With Battery Inserted After Wireless Power is Enabled

10 Power Supply Recommendations

The BQ51013C requires a Qi-compatible transmitter as its power source.

11 Layout

11.1 Layout Guidelines

- Keep the trace resistance as low as possible on AC1, AC2, and BAT.
- Detection and resonant capacitors must be as close to the device as possible.
- COMM, CLAMP, and BOOT capacitors must be placed as close to the device as possible.
- Via interconnect on PGND net is critical for appropriate signal integrity and proper thermal performance.
- High frequency bypass capacitors must be placed close to RECT and OUT pins.
- ILIM and FOD resistors are important signal paths and the loops in those paths to PGND must be minimized.

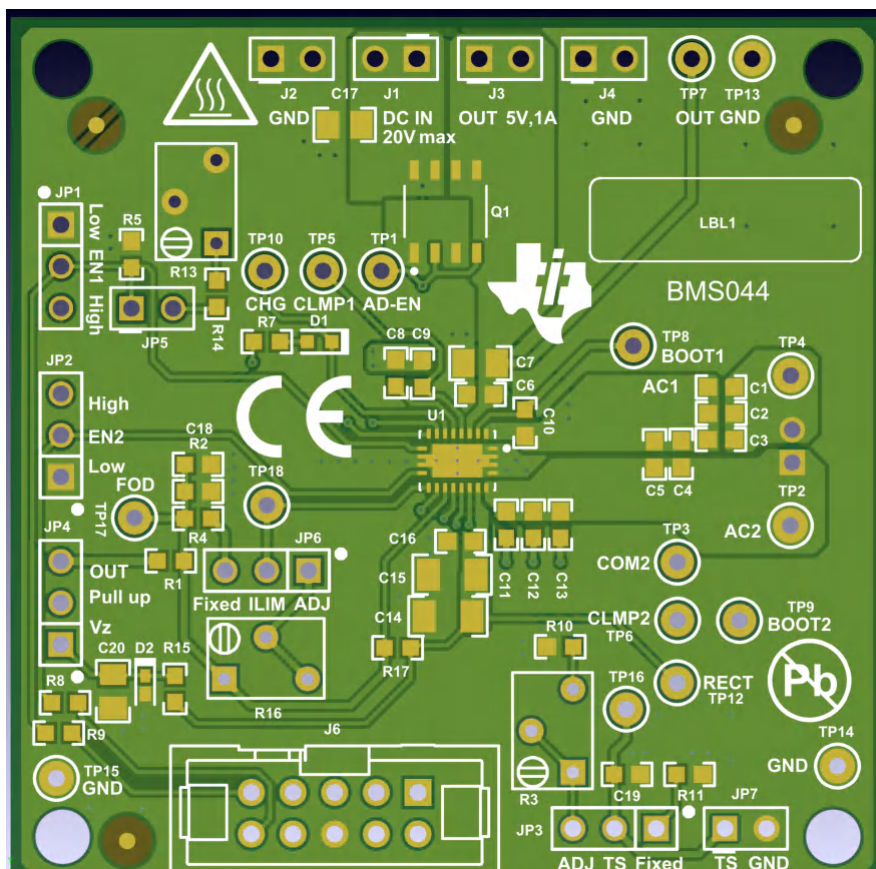
Signal and sensing traces are the most sensitive to noise; the sensing signal amplitudes are usually measured in mV, which is comparable to the noise amplitude. Make sure that these traces are not being interfered by the noisy and power traces. AC1, AC2, BOOT1, BOOT2, COMM1, and COMM2 are the main source of noise in the board. These traces should be shielded from other components in the board. It is usually preferred to have a ground copper area placed underneath these traces to provide additional shielding. Also, make sure they do not interfere with the signal and sensing traces. The PCB should have a ground plane (return) connected directly to the return of all components through vias (two vias per capacitor for power-stage capacitors, one via per capacitor for small-signal components).

For a 1-A fast charge current application, the current rating for each net is as follows:

- AC1 = AC2 = 1.2 A
- OUT = 1 A
- RECT = 100 mA (RMS)
- COMMx = 300 mA
- CLAMPx = 500 mA
- All others can be rated for 10 mA or less

For the RHL package, the thermal pad should be connected to ground to help dissipate heat.

11.2 Layout Example



For the RHL package, the thermal pad should be connected to ground to help dissipate heat.

Figure 11-1. BQ51013C Layout Schematic

12 Device and Documentation Support

12.1 Device Support

12.1.1 Third-Party Products Disclaimer

TI'S PUBLICATION OF INFORMATION REGARDING THIRD-PARTY PRODUCTS OR SERVICES DOES NOT CONSTITUTE AN ENDORSEMENT REGARDING THE SUITABILITY OF SUCH PRODUCTS OR SERVICES OR A WARRANTY, REPRESENTATION OR ENDORSEMENT OF SUCH PRODUCTS OR SERVICES, EITHER ALONE OR IN COMBINATION WITH ANY TI PRODUCT OR SERVICE.

12.1.2 Development Support

The tool for Foreign Object Detection (FOD) Calibration can be found on the web folder under [Tools and software](#).

12.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. Click on *Notifications* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

12.3 Support Resources

[TI E2E™ support forums](#) are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

12.4 Trademarks

TI E2E™ is a trademark of Texas Instruments.
All trademarks are the property of their respective owners.

12.5 Electrostatic Discharge Caution



This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

12.6 Glossary

[TI Glossary](#) This glossary lists and explains terms, acronyms, and definitions.

13 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (October 2024) to Revision A (May 2025)	Page
• Changed WPC v2.0 to WPC v1.3 throughout the data sheet.....	1
• Updated Features.....	1
• Deleted Dynamic V _{RECT} Threshold 1-3 in Electrical Characteristics.....	8
• Deleted several graphs in Typical Characteristics.....	11
• Updated Details of a Qi Wireless Power System and BQ51013C Power Transfer Flow Diagrams section.....	16
• Deleted Dymanic Rectifier Control and Dynamic Efficiency Scaling sections.....	16
• Updated R _{LIM} Calculations section.....	18
• Deleted Receiver Coil Load-Line Analysis section.....	27
• Updated Using the BQ51013C as a Wireless Power Supply section.....	29
• Updated Recommended RX Coils section.....	31

• Deleted Application Curves section.....	32
• Updated Application Curves section.....	33
• Changed 800 mA to 400 mA in Wireless and Direct Charging of a Li-Ion Battery at 400 mA section.....	34
• Changed 800 mA to 400 mA in Design Requirements section.....	34
• Updated Detailed Design Procedure section.....	34
• Updated Application Curves section.....	35

14 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package Pins	Package qty Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
BQ51013CRHLR	Active	Production	VQFN (RHL) 20	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BQ51013C
BQ51013CRHLR.A	Active	Production	VQFN (RHL) 20	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	BQ51013C

⁽¹⁾ **Status:** For more details on status, see our [product life cycle](#).

⁽²⁾ **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

⁽³⁾ **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

⁽⁴⁾ **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

⁽⁵⁾ **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

⁽⁶⁾ **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

Important Information and Disclaimer:The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

OTHER QUALIFIED VERSIONS OF BQ51013C :

- Automotive : [BQ51013C-Q1](#)

NOTE: Qualified Version Definitions:

- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

TAPE AND REEL INFORMATION



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
BQ51013CRHLR	VQFN	RHL	20	3000	330.0	12.4	3.71	4.71	1.1	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
BQ51013CRHLR	VQFN	RHL	20	3000	367.0	367.0	35.0

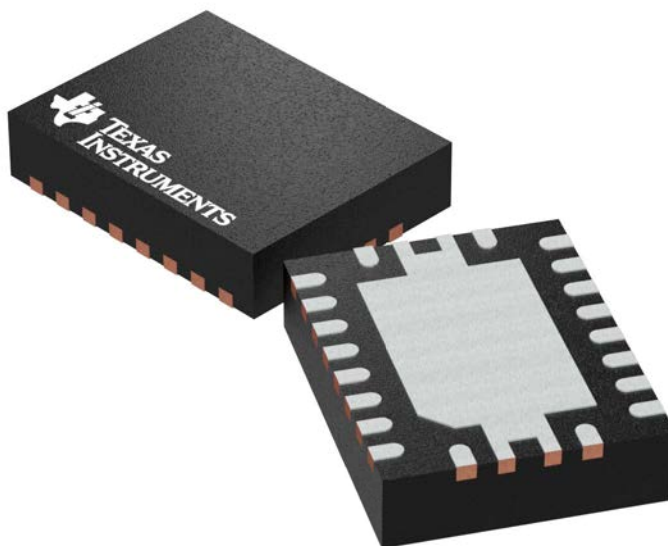
GENERIC PACKAGE VIEW

RHL 20

VQFN - 1 mm max height

3.5 x 4.5 mm, 0.5 mm pitch

PLASTIC QUAD FLATPACK - NO LEAD



Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

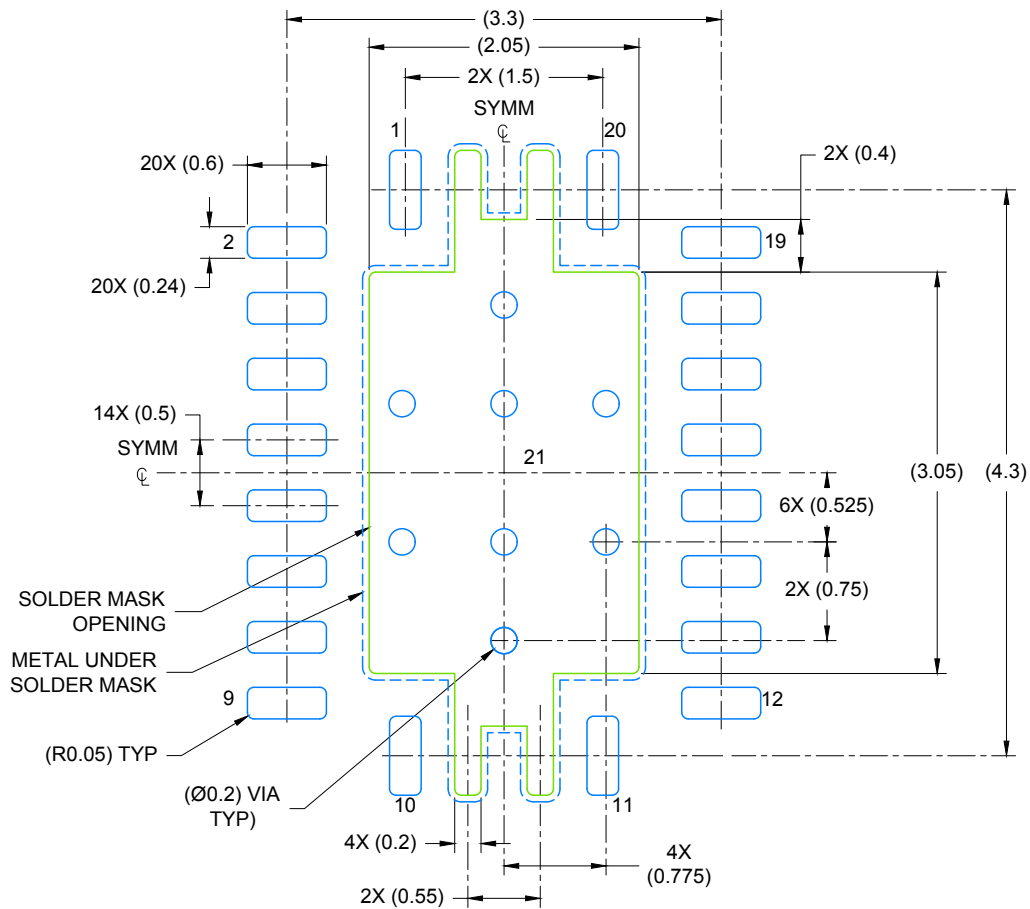
4205346/L

VQFN - 1 mm max height

[illegible]

NOTES:

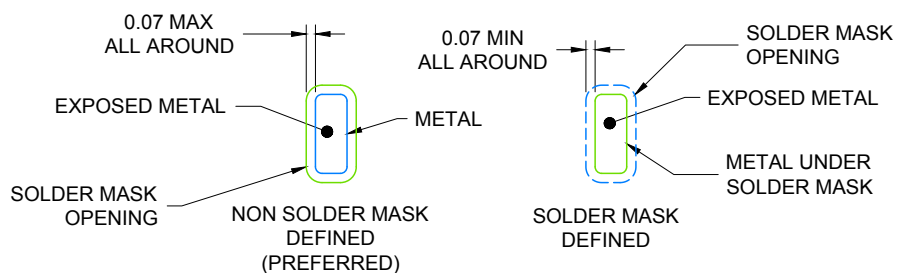
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.



LAND PATTERN EXAMPLE

EXPOSED METAL SHOWN

SCALE: 18X

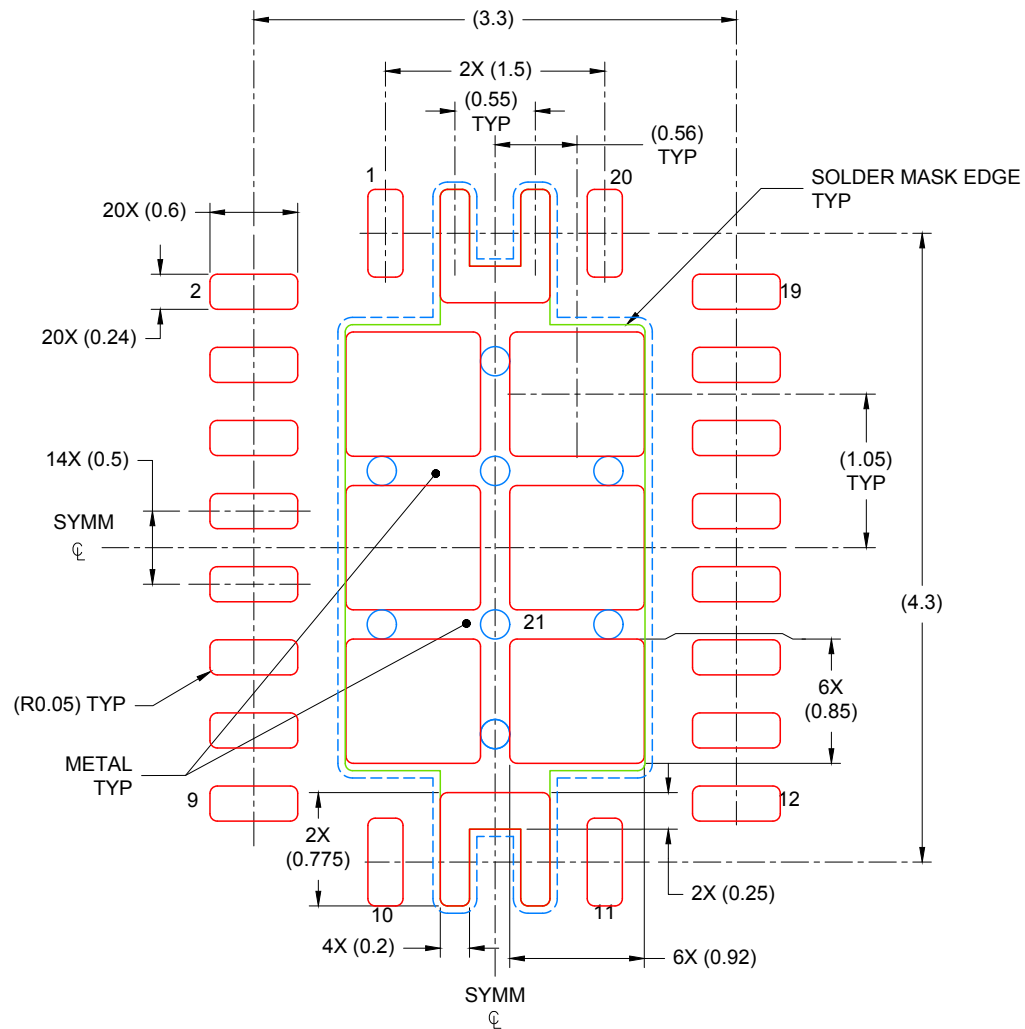


SOLDER MASK DETAILS

4219071 / A 05/2017

NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/sluea271).
5. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
6. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.



SOLDER PASTE EXAMPLE
 BASED ON 0.1mm THICK STENCIL

EXPOSED PAD
 75% PRINTED COVERAGE BY AREA
 SCALE: 20X

4219071 / A 05/2017

NOTES: (continued)

7. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations..

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you fully indemnify TI and its representatives against any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#), [TI's General Quality Guidelines](#), or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products. Unless TI explicitly designates a product as custom or customer-specified, TI products are standard, catalog, general purpose devices.

TI objects to and rejects any additional or different terms you may propose.

Copyright © 2025, Texas Instruments Incorporated

Last updated 10/2025