bqTESLA™
Making Wireless Power a Reality!

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1Q 2013

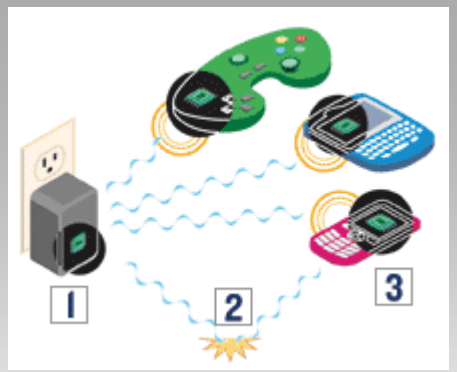
Texas Instruments

Agenda

- Introduction to Wireless Power
- WPC – The Wireless Power Consortium
- bqTESLA™ Solutions from Texas Instruments

Wireless Power Technologies

Conductive Charging (Wildcharge, Duracell)



RF Wireless Charging (Powercast)

Palm, Powermat

Toothbrush, Witricity

WIRELESS POWER CONSORTIUM

Standardization & Interoperability will drive growth !

QI is the solution TODAY !!

Texas Instruments

Market TAM Forecast

Standardization / Interoperability will drive growth !!

By Application

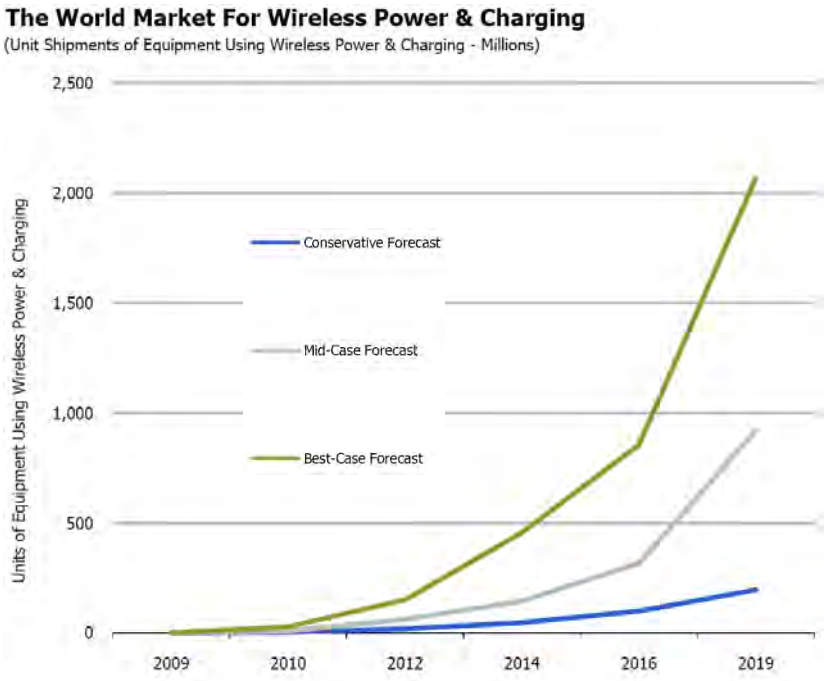
Millions of Units (2009 & 2019)

Application Area	2009	2019	CAGR
Cell Phones	1.3	641.7	85.9%
Games Contollers	0.0	94.3	154.8%
Notebooks	0.0	34.8	137.6%
All Other Portable	0.0	82.7	127.5%
All Other Apps	0.1	69.5	87.5%
Total	**1.5**	**922.9**	**90.5%**

By Implementation

Millions of Units (2009 & 2019)

Supplier	2009	2019	CAGR
Aftermarket Receivers	1.5	331.0	72.0%
Integrated Receivers	0.0	591.9	238.0%
Others	**1.5**	**922.9**	**90.5%**



Aug 17, 2011: *IMS Research, a technology consultancy, released a report on Monday saying by their calculations, the industry will explode within the coming five years. While only worth roughly $100 million in 2010, IMS expects the* ***2016*** *value* ***to be around $4.5 billion****. That's an* ***annual growth rate*** *of about* ***86.5 percent****.*

Texas Instruments

Qi Products Available Today

WIRELESS POWER CONSORTIUM

Powered by TI's bqTESLA

2-device charge pad

iPhone 3G/3GS case

BB8900 Curve door

iPhone 4 sleeve

HTC Rezound™

Verizon (LG) charge pad

Motorola DROID ™ 4

Motorola DROID ™ Bionic

HTC Incredible 2™

HTC ThunderBolt™

Motorola DROID™ 3

Pantech Breakout

HTC 8X

HTC Droid DNA

LG Lucid™

LG Revolution™

ARROWS Kiss™ F-03D

Sharp AQUOS™ SH-02D

Google Nexus 4

Samsung DROID ™ CHARGE

Nokia Lumia 920/820

DT900

Eluga™ V P-06D

QE-TM101

Sharp AQUOS™ f-SH13C

NEC MEDIA™ PP N-01D

Sharp STYLE SH-05D

Texas Instruments

bqTesla™ Inside Accessory

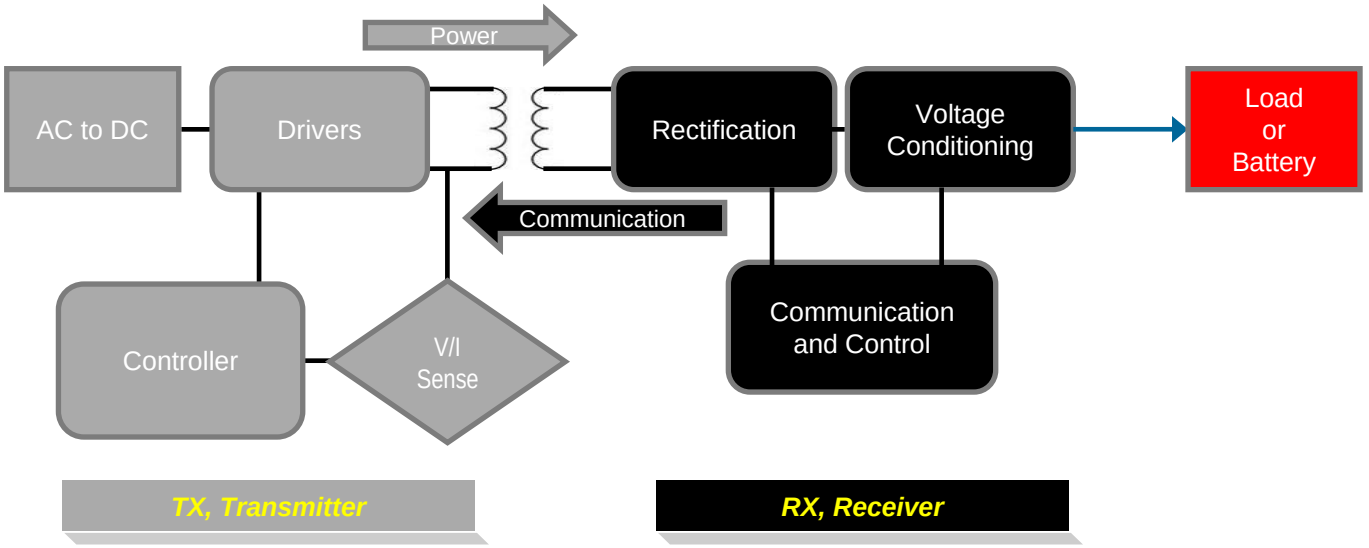
TX/RX Module

Accessories

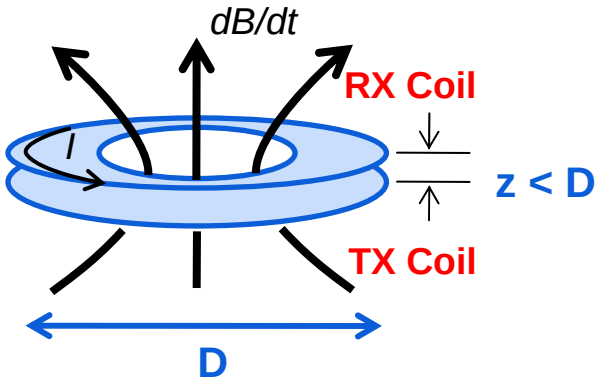
For Table Mount

To Verify if the product is really WPC Certificated→ http://www.wirelesspowerconsortium.com/products/

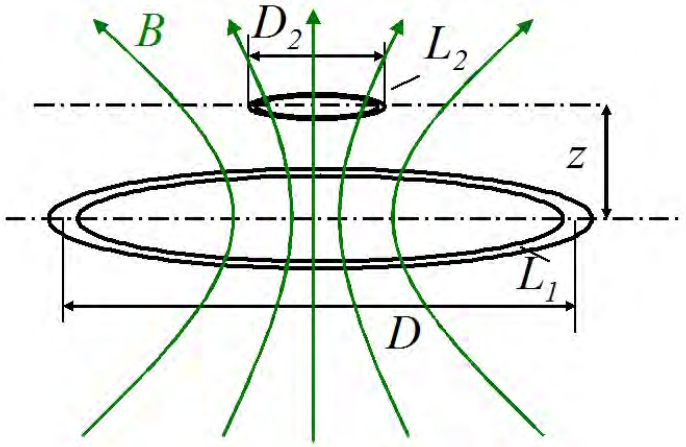
Inductive Power System Overview



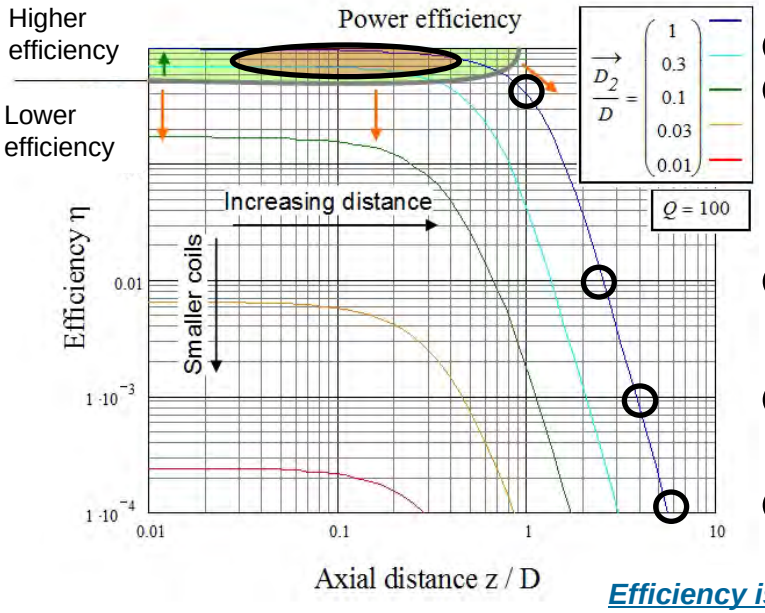
- Power transmitted through shared magnetic field
  - Transmit coil creates magnetic field
  - Receive coil in proximity converts field into voltage
  - Shielding material on each side directs field
- Power transferred only when needed
  - Transmitter waits until its field has been perturbed
  - Transmitter sends seek energy and waits for a digital response
  - If response is valid, power transfer begins
- Power transferred only at level needed
  - Receiver constantly monitors power received and delivered
  - Transmitter adjusts power sent based on receiver feedback
  - If feedback is lost, power transfer stops



System Efficiency Dependencies



- Coupling between coils
  - Distance (z) between coils
  - Ratio of diameters (D_2 / D) of the two coils
  - Physical orientation
- Quality factor
  - Ratio of inductance to resistance
  - Geometric mean of two Q factors
- Uncoupled field has no losses
- Near field allows TX to “see” RX

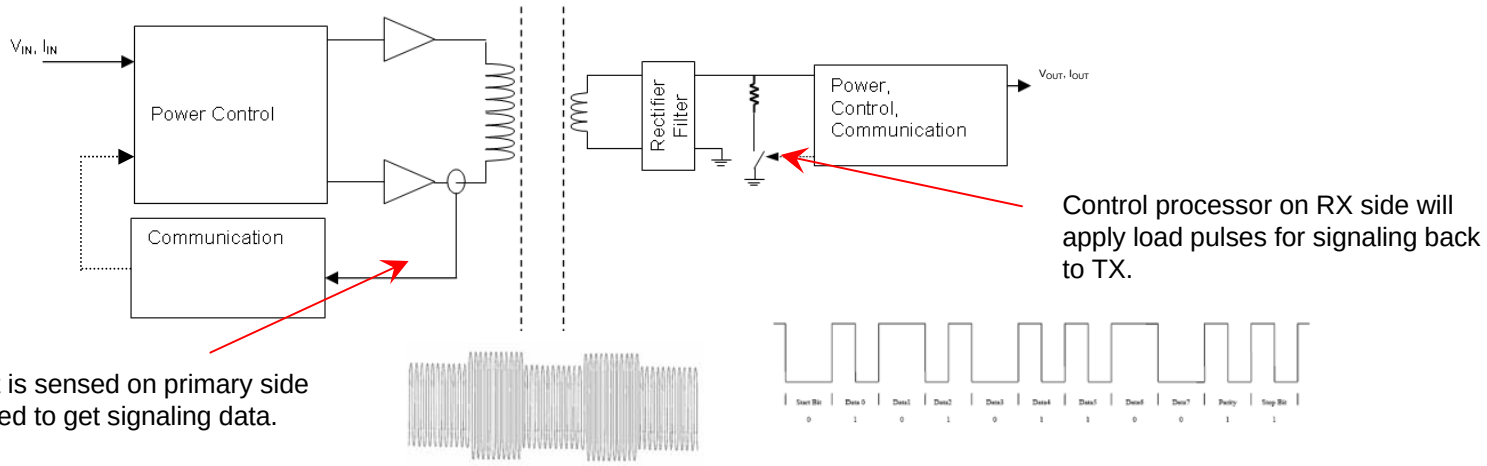


- Optimal operating distance
- 40% at 1 diameter
- 1% at 2.5 diameter
- 0.1% at 4 diameters
- 0.01% at 6 diameters

Efficiency is Optimal when Coils are Less than One Diameter apart

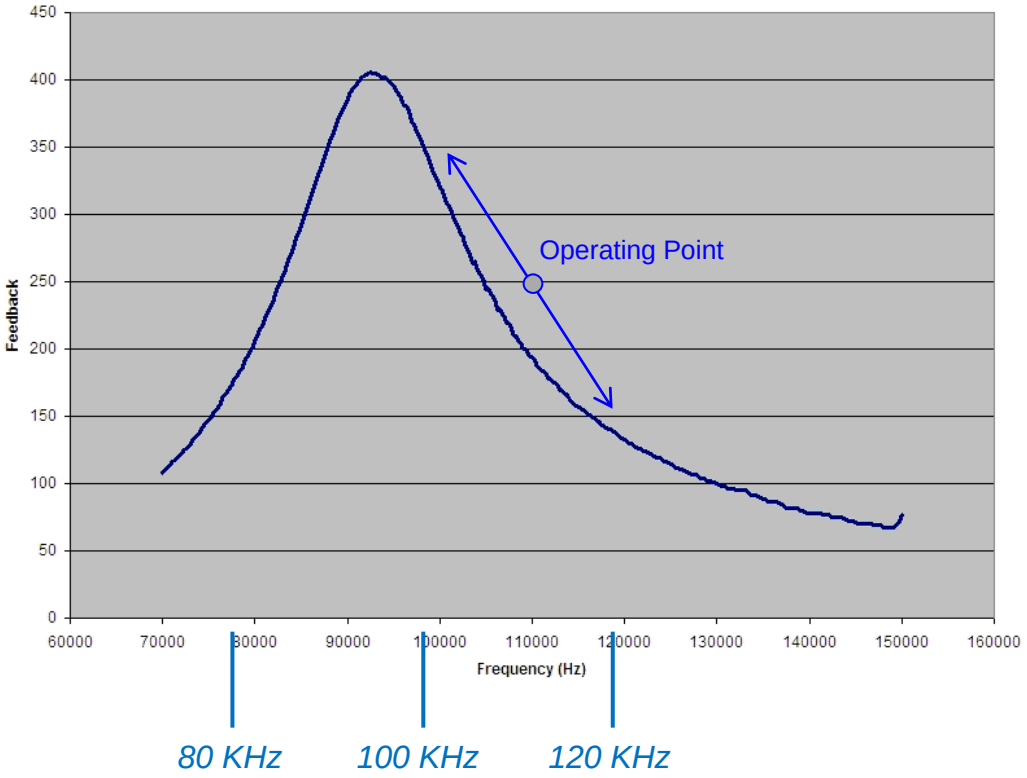
Communication - Basics

- **Primary side controller must detect that an object is placed on the charging pad.**
  - When a load is placed on the pad, the primary coil effective impedance changes.
  - “Analog ping” occurs to detect the device.
- **After an object is detected, must validate that it is WPC-compatible receiver device.**
  - “Digital Ping” – transmitter sends a longer packet which powers up the RX side controller.
  - RX side controller responds with signal strength indicator packet.
  - TX controller will send multiple digital pings corresponding to each possible primary coil to identify best positioning of the RX device.
- **After object is detected and validated, Power Transfer phase begins.**
  - RX will send Control Error Packets to increase or decrease power level



Switching Frequency Variation

- System operates near resonance for improved efficiency.
- Power control by changing the frequency, moving along the resonance curve.
- Modulation using the power transfer coils establishes the communications.
- Feedback is transferred to the primary as error.



WPC operation frequency range : 110-205kHz

Metal Object SENSING and PROTECTING

- **Metal between TX and RX**
  - Metal cover should not exist between TX & RX in design
  - Protection for User accidently case is needed
  - Energy Lost in Foreign Metals (Eddy Current)
  - Undesired Heating and Safety Issue

- **Two methods to detect foreign object via monitoring power losses**

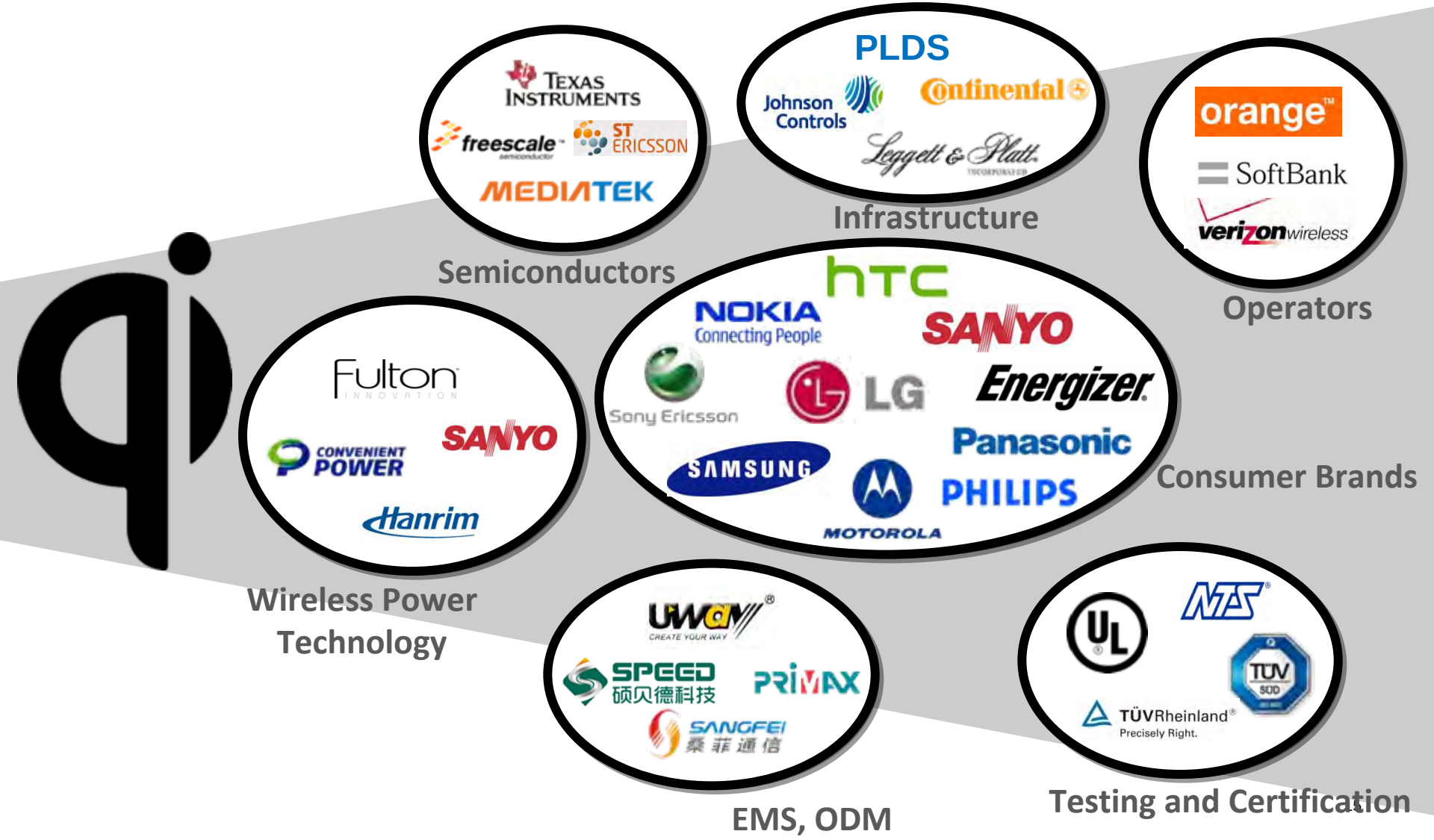
  PMOD (TI only, Parasitic Metal Object Detection)
  - A quadratic polynomial approximation based on the Rectified Power on Rx to calculate losses in the TX-RX system.

  FOD (MUST in WPC1.1 , Foreign Object Detection)
  - This uses specific information from characterized Rx to improve the accuracy of Foreign Object Detection in WPC system (looking at Received Power from Rx, and power lost in shield, coil, rectifier and control circuit).
  - FOD is finalized in WPC 1.1 spec. TI solution will move to FOD (from PMOD) instead of using PMOD.

WPC
Wireless Power Consortium

WIRELESS POWER CONSORTIUM

WPC Membership growth



WPC - Wireless Power Consortium

- History
  - http://www.wirelesspowerconsortium.com/
  - Held its first meeting on Dec-18, 2008 in Hong Kong.
  - Published the Qi low power specification in Aug 2009, 18 months after the first meeting. The first product was certified in Sep 2009.
- Today, WPC1.1 now
  - WPC today define low power applications (<5W).
  - Annual fee is US$ 15k/20k for join Associated/Regular membership
  - 141 members, 133 certificated products (As of Jan-30, 2013)
  - The Consortium is working on
    - 10W-15W extension
    - 120W medium power
    - 2kW, wireless power in Kitchen
- **Membership & QI Certification**
  - WPC Spec. Part 1 Specification is open for public download.
  - Part 2 & 3 (Performance & Compliance) only limited to member access.
  - WPC Lab only accept members' product for certification.

WPC1.1, Today

- WPC1.0 to WPC1.1
  - WPC1.1 announced in Mar, 2012, WPC Lab is ready for WPC1.1 certification from Dec 2012
  - WPC1.0 certification will stop in May 2013, WPC1.0 product cannot be sold after May 2014.
  - TI is the first solution supplier for WPC1.1
  - QI certification Product List → http://www.wirelesspowerconsortium.com/products/

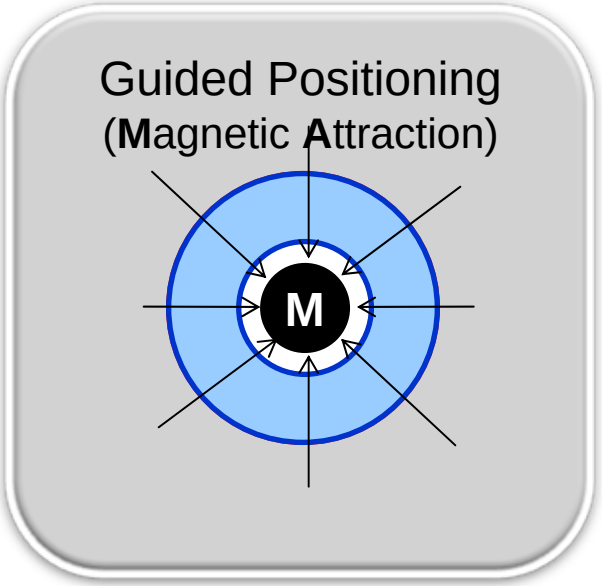
Showing the latest certified products

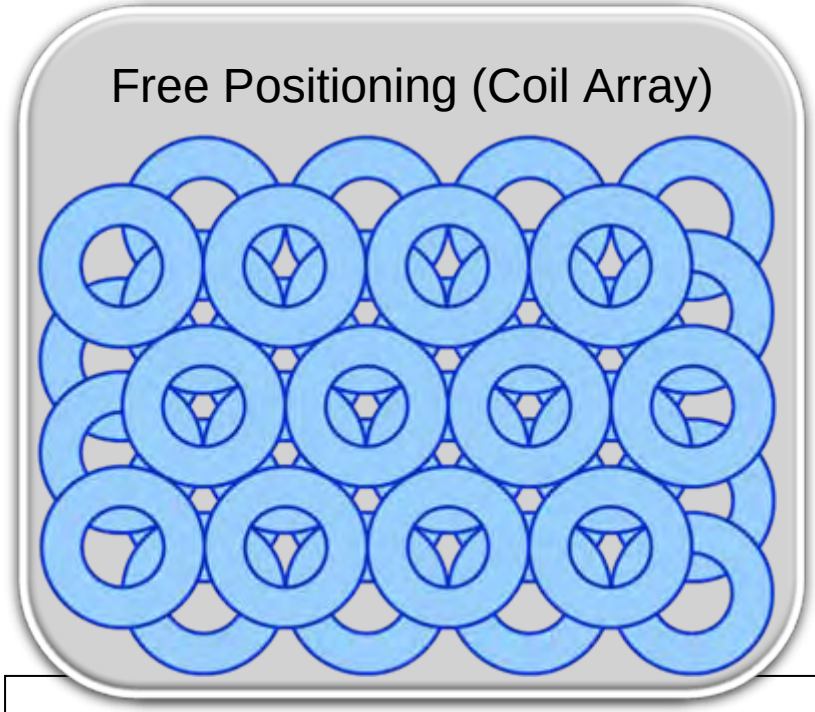
Showing the latest 20 of the 133 products in total

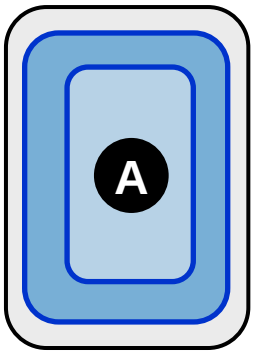
Product Name	Brand Name	Type Number	Registration Date
wireless charger	SCUD (Fujian) Ele...	WS001	Jan 11, 2013
BQ500410A	Texas Instruments	BQ500410A EV...	Jan 10, 2013
BQ500211A	Texas Instruments	BQ500211A EV...	Jan 10, 2013
Wireless Charging...	Lepower	LSR100	Jan 6, 2013

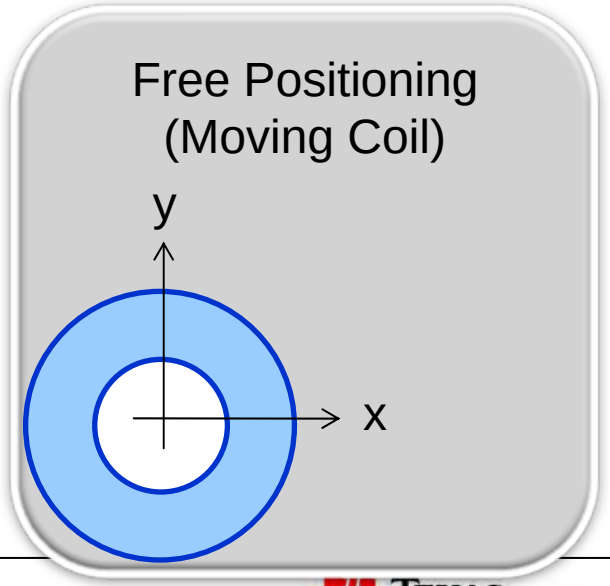
WPC TX Design Freedom

- **Guided Positioning**
  - Easy Design, Low cost
  - Option with or without Magnet
  - bq500210 (A1/A10*), bq500211 (A5, A11*)
  - RFP is a better solution, BQ500410 (A6)
- **Moving Coil**
  - Sensor Array and Motor required, higher cost and complex design
- **Coil Array**
  - Coil cost and 3-layer coil result high DCR

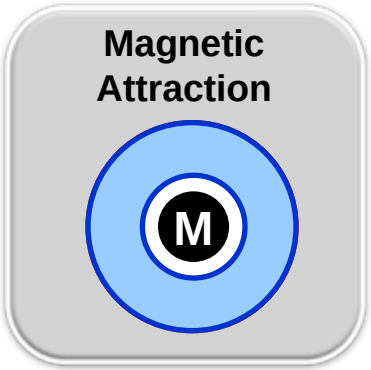


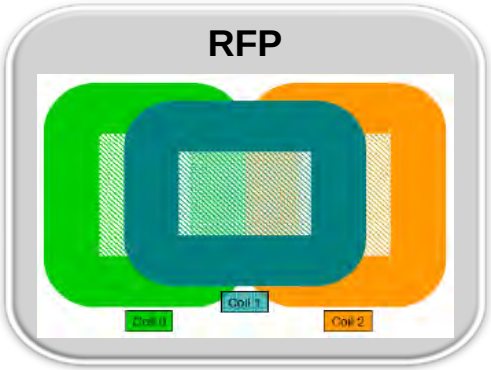


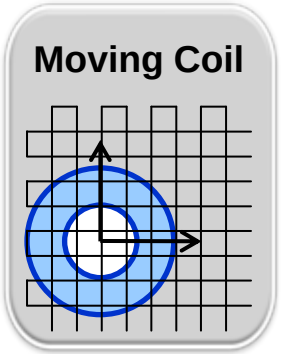


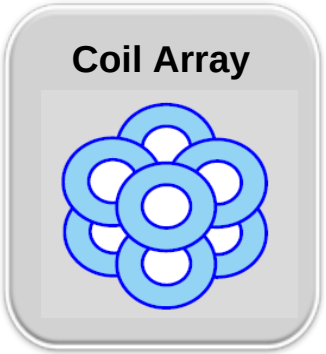


WPC TX Option - Single Bay









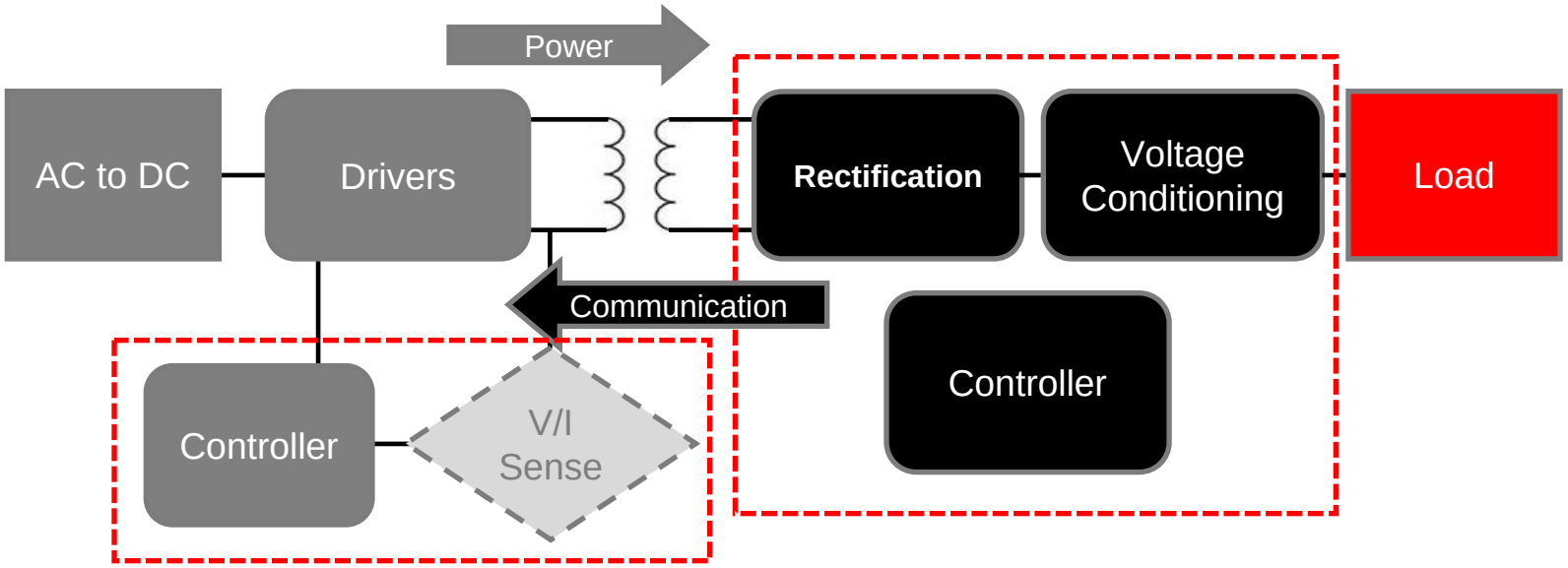
	A1/A5, A10/A11	A6	A2	B1
Charging Area	18x18 – Initial 32x32 - Max	70x20 - Initial 80x35 - Max	--	36x34
Coil #	1	3	1	7
Vin	19V/5V	12V	3-12V	12V
Eff	>75%	>70%	?	<65%
TI Device	BQ500210/211	BQ500410A	N/A	N/A

Comparison

- A1/A5, Simple design. Can be extend to A10/A11 TX design
- A6 (RFP), Maximum charging Area, (5V input can be done by additional boost converter)
- A2, Require sensor array and 2 motor for moving coil, not fit to automotive application, complicated design
- B1, small coil and thin wire cause high coil DCR, require a lot of MOSFET for coil multiplexor, complicated design

bqTESLA™ Solutions

TI bqTESLA Solutions



TX
- bq500210 *(G2)*
- bq500211/A *(G2)*
- bq500410A *(G2)*
- bq500110 *(G1)*

RX
- bq5101x/5x single chip *(G2)*
- bq25046+MSP430bq1010 *(G1)*

- Gen1, Based on discrete components (Released in Nov 2010)
- Gen2, Integrated solutions that will optimize performance, size and cost
- TI bqTesla EVMs are all WPC certificated

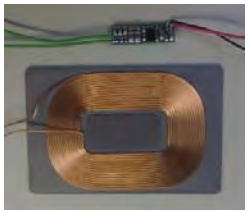
bqTESLA™ EVM kit

TI bqTesla EVMs are all WPC certificated !! → WPC website

bqTesla100LP
Gen1 TX+ Gen1 RX

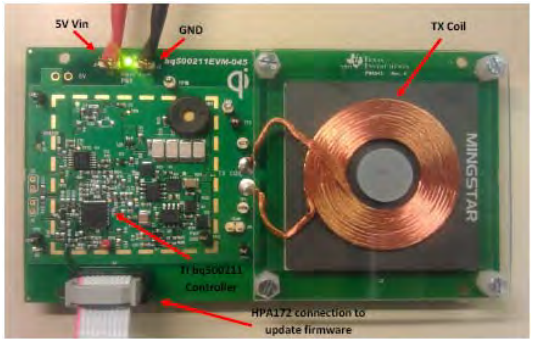
bqTesla150LP
Gen1 TX+ Gen2 RX (BQ51013)

Gen2 RX 2.5W design
PCB 15x5x1.5mm3
BOM count 20
80% Area reduction vs Gen1 !!



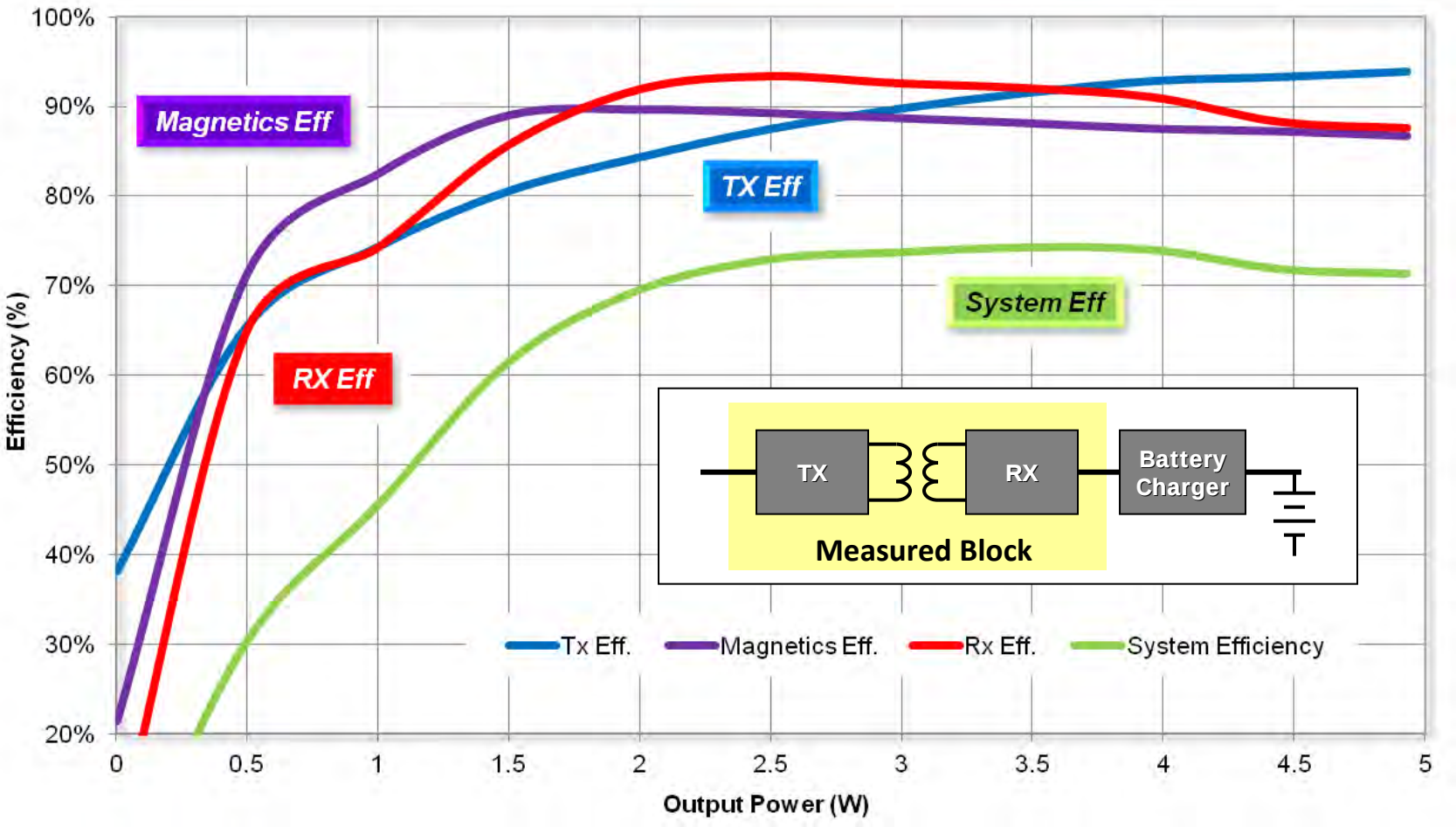
Gen2 TX 19V (BQ500210)

Gen2 TX 5V (BQ500211)



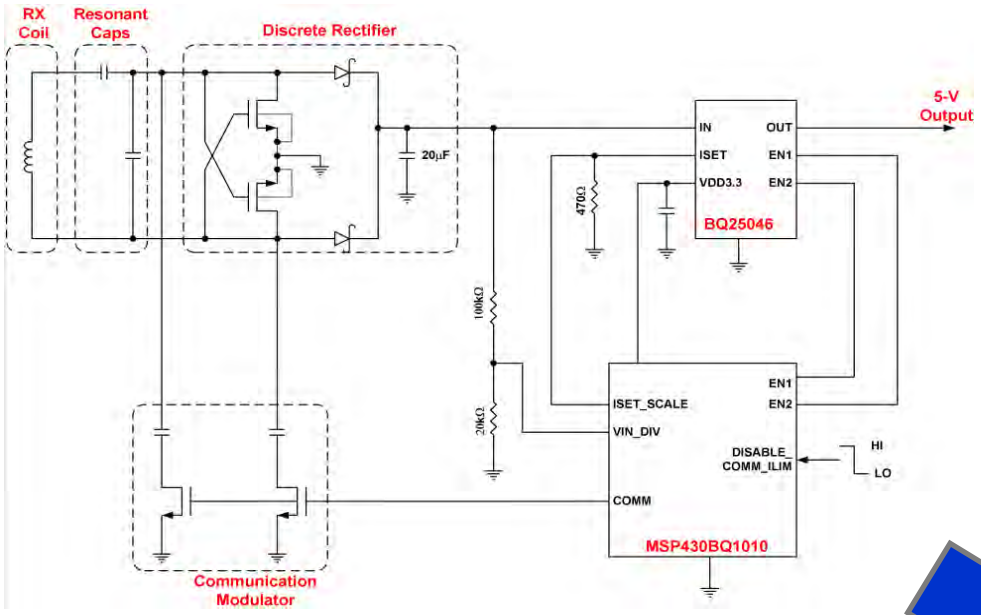
bqTesla System Efficiency Breakdown

- Efficiency is RX Coil design dependent
- Measured from BQ500210 TX DC input to BQ51013 RX 5V output

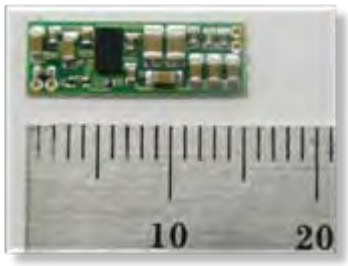


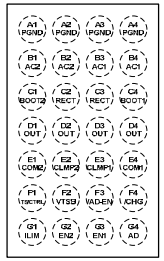
bqTESLA™ RX

RX – Integration

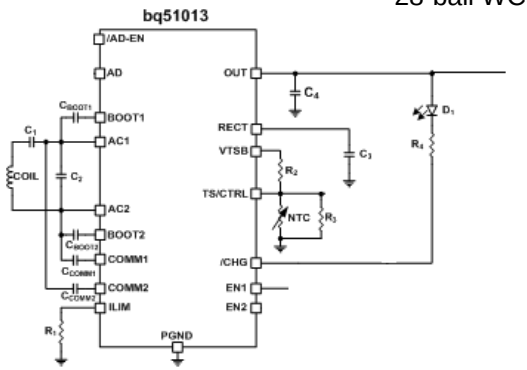


- Gen1, Discrete solution
- Less efficiency and higher cost
- Not Recommended for New Design



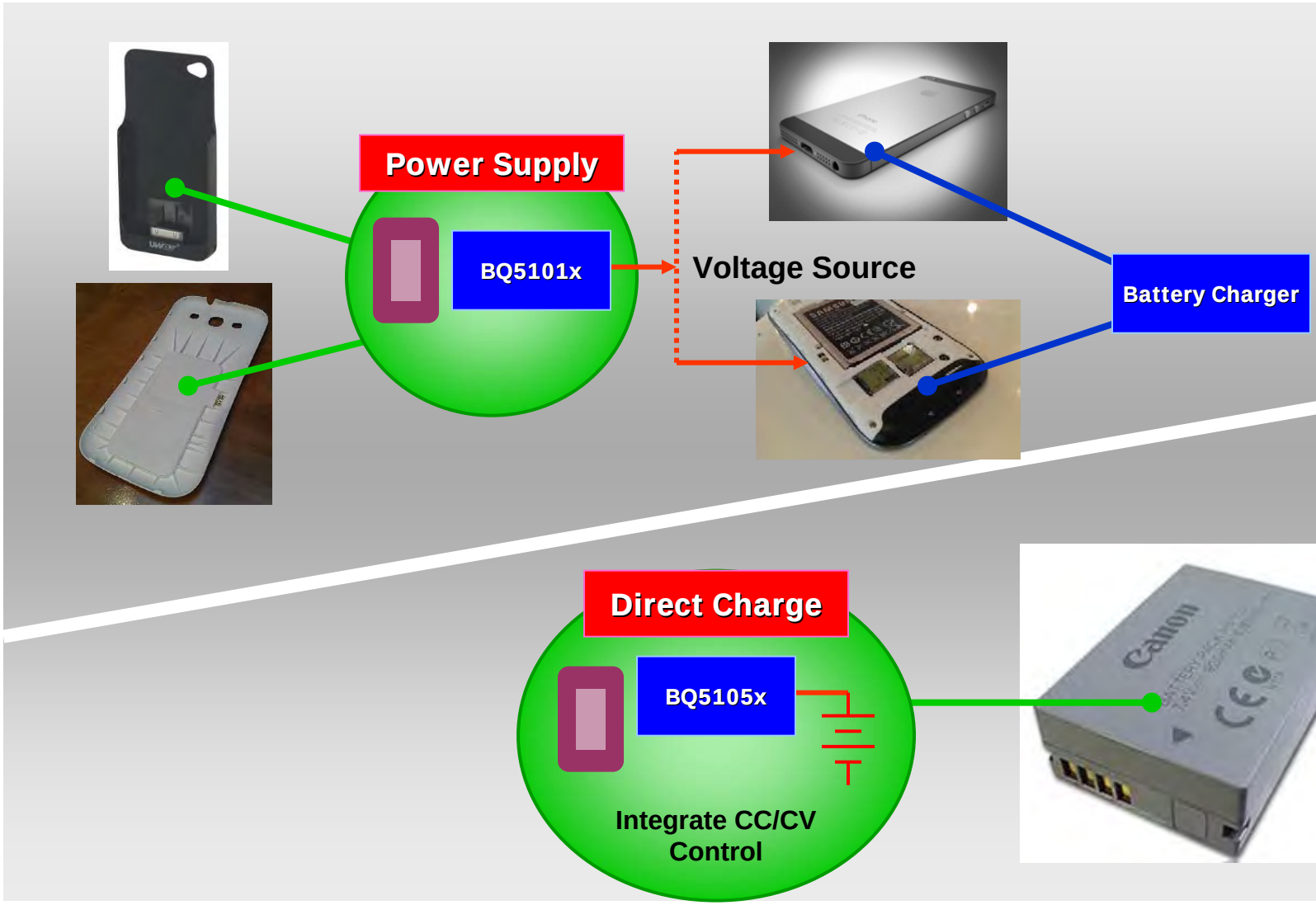


3.0x1.8 mm
28-ball WCSP

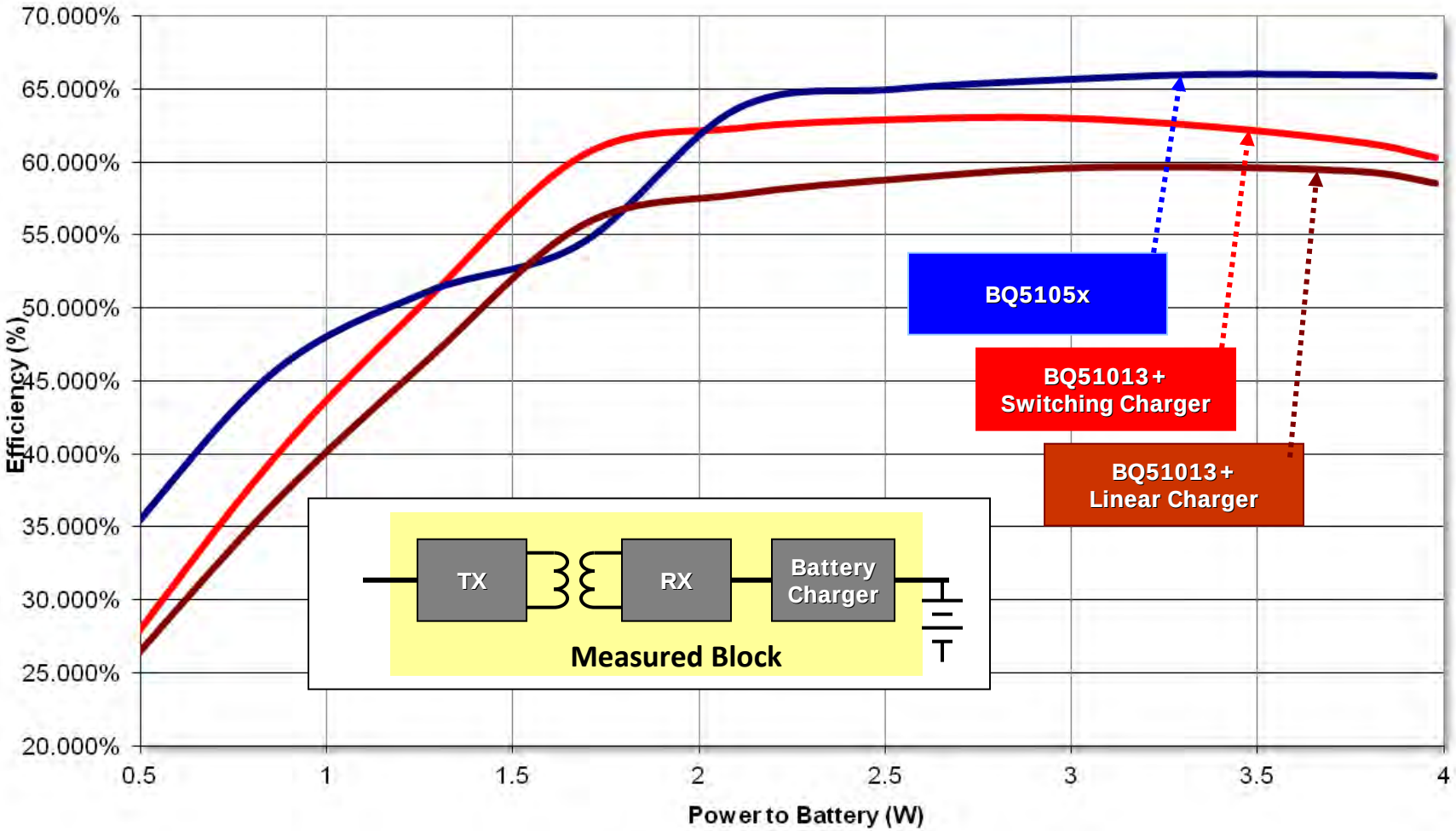


- Gen2, Single Chip
- Sync. Rectifier, Efficiency optimization
- QFN Package available

RX, bq51k Family



System Architecture for Efficiency



System Efficiency Consideration

Stage	Condition	Efficiency
AC/DC Adaptor	5V @10W	80%
Wireless Power	TI Gen2 TX+RX	75%
USB Cable	--	100%
Linear Charger	5V to 3.6V	72%
Switching Charger	BQ24156A	90%

Eff = 80% x 100% x 72% = 57.6 %

Eff = 80% x 75% x 72% = 43.2 %

Eff = 80% x 75% x 90% = 54.0 %

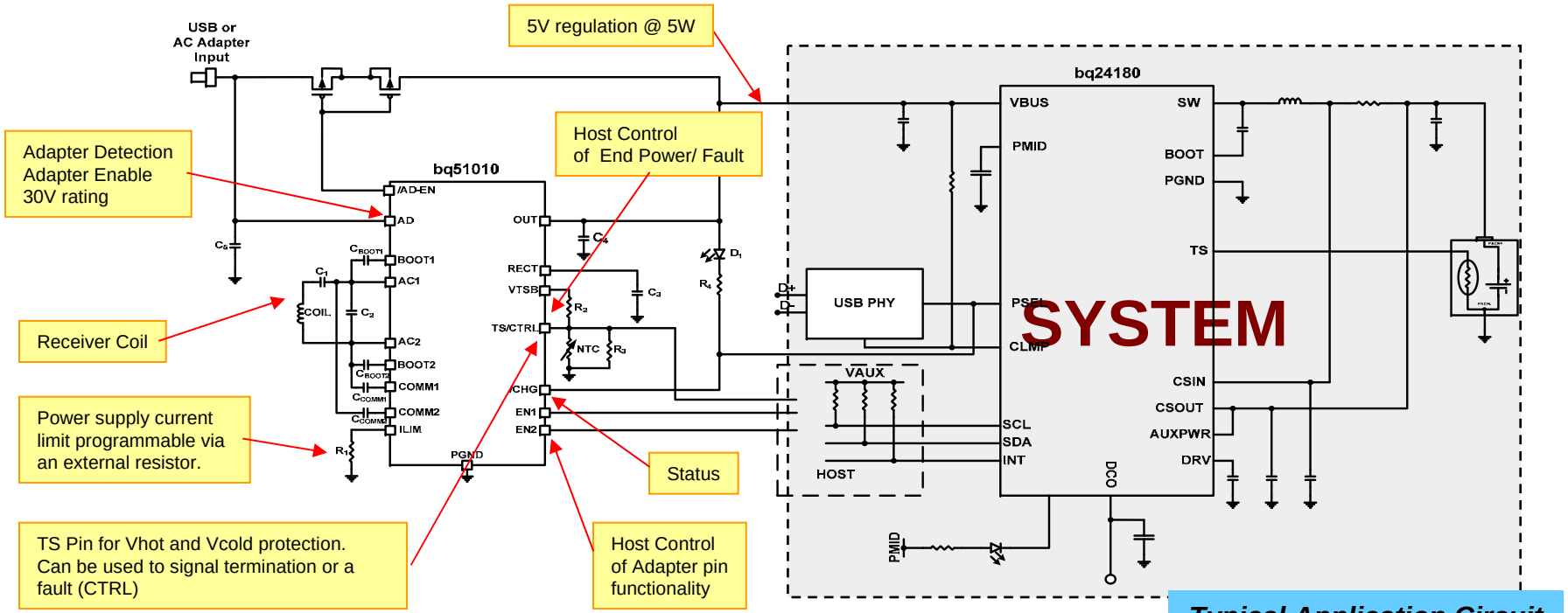
- Efficiency Improvement
  - For most of the consumer portable product, efficiency bottle neck is on linear charger, or on adaptor in case of low cost adaptor is used.
  - Efficiency drop due to wireless power can be making up by using switching charger
  - Wireless Power Efficiency Improvement can be done by changing TX/RX coil, but the cost will increase significantly.
  - Using 10V wireless power output with switching charger is the cost effective way to improve overall efficiency

Gen2 RX, bq51k Family

Device	Function	WPC Vers Compliant	$V_{OUT(REG)}$ (V)	I_{OUT} Max (A)	FOD	Dynamic Efficiency Scaling	Dynamic Communication Limit	Charge Status 100%	Over Current Shutdown	Over Temperature	External V_{IN} Switch	AC Adapt OVP (V_{RECT})	AD Adapt OVP	Host Communications	Availability
bq51011	Current-limited Power Supply *(Power Level = 2-5W)*	1.0	5	1.5	-	-	-	-	-	✓	✓	✓	-	Stand Alone	Released 2011
bq51013	Regulated Power Supply *(Power Level = 2-5W)*	1.0	5	1.5	-	-	-	-	-	✓	✓	✓	-	Stand Alone	Released 2011
bq51013A	Regulated Power Supply *(Power Level = 0-5W)*	1.0	5	1.5	-	✓	✓	-	-	✓	✓	✓	-	Stand Alone	Released 2012
New															
bq51013B	Regulated Power Supply *(Power Level = 0-5W)*	1.1	5	1.5	✓	✓	✓	-	-	✓	✓	✓	-	Stand Alone	Released 2012
bq51050B/ 51B	Li-Ion Battery Charger *(Power Level = 0-5W)*	1.1	**4.2 4.35**	1.5	✓	-	-	-	-	-	✓	✓	-	Stand Alone	Released 2012

bq51013x – General 5V Power Supply

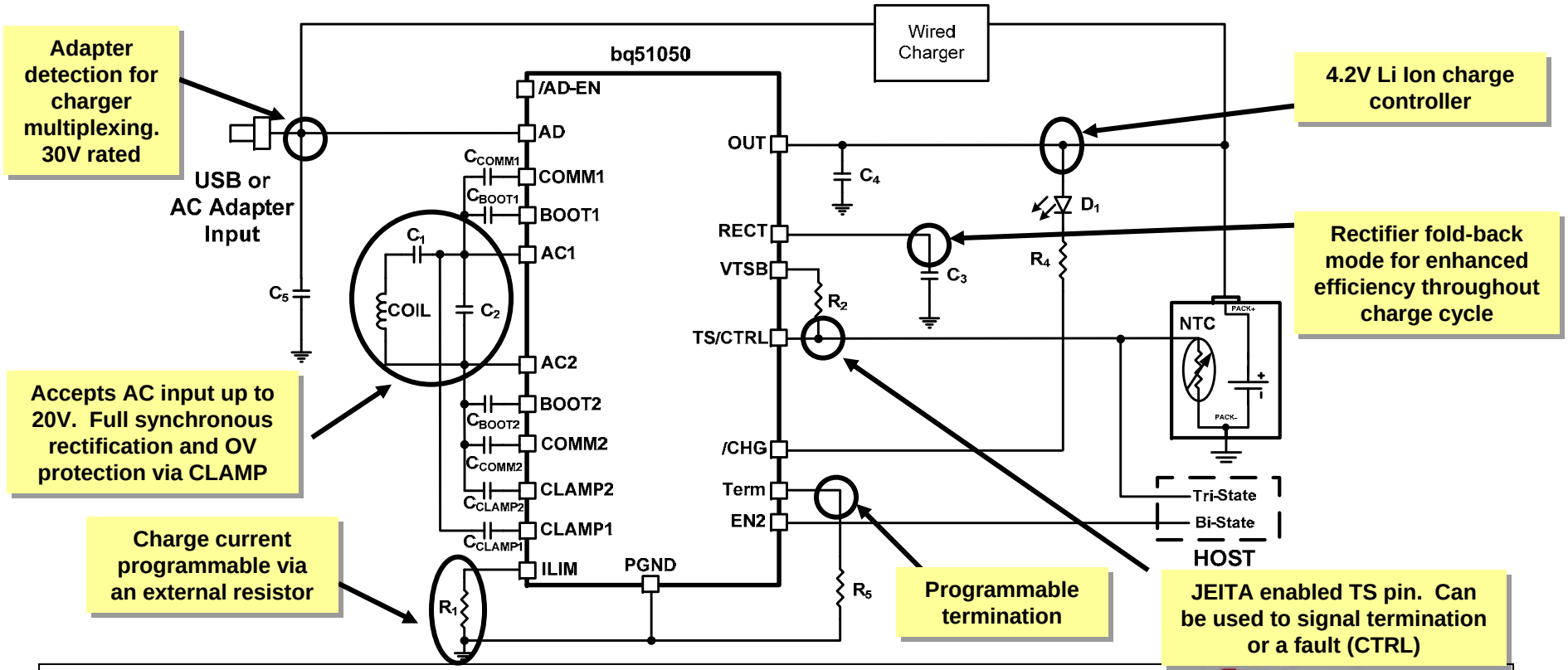
- Integrates synchronous rectification, voltage conditioning, communication control
- bq51013x acts as a *Power Supply* to deliver 5V to the VIN pin of the system charger
- bq51013x *automatically* selects between AC adapter/USB and wireless input power sources
- Provides adjustable *current limit protection* and *coil overvoltage protection*
- Host interface can enable *OTG mode* via **EN1** = '1' or charge termination with **EN1** = **EN2** = '1'



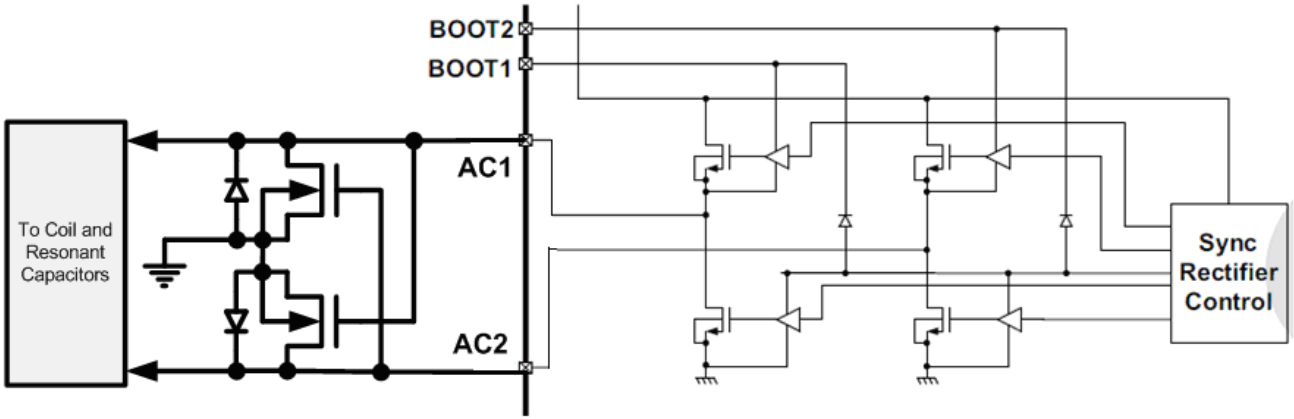
Typical Application Circuit

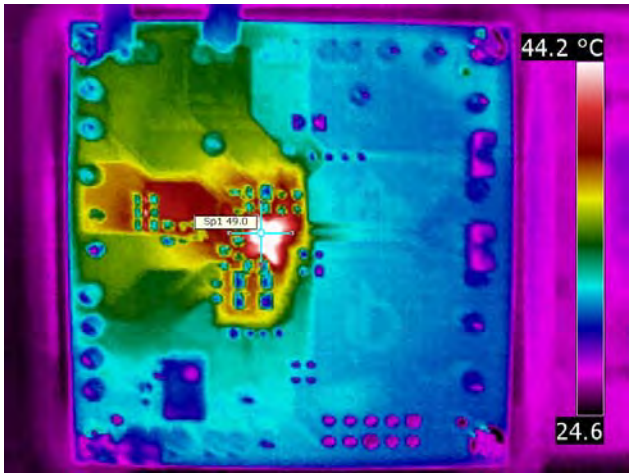
bq5105xB - Direct Charge Application

- Integrated full synchronous rectifier, WPC control, and Lithium Ion charging algorithm
- Rectifier tracks the battery voltage to within a drop-out voltage to ensure high efficiency during a full charge cycle (rectifier fold-back mode)
- Jeita enabled TS pin, and termination EPT
- Supports OTG while wirelessly charging (EN2 must be driven high)

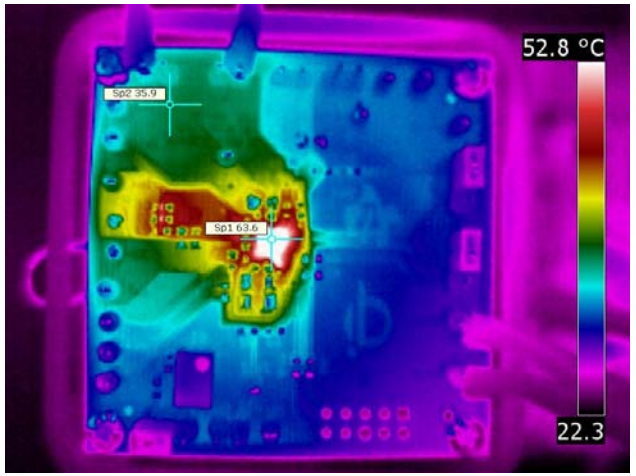


External Rectifier for Thermal Improvement





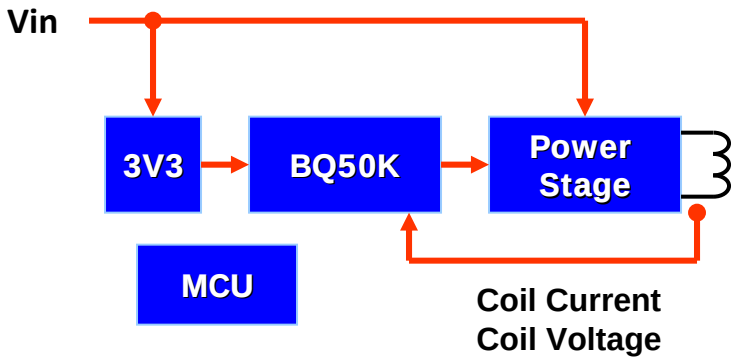
Case Temp = 49°C
5V OUT with EXTERNAL SYNC FETS



Case Temp = 63.6°C
with 5V OUT

bqTESLA™ TX

Gen2 TX System Diagram



- **Simple Function Block**
  - **BQ50K,** Main Controller
  - **Power Stage**, FET and FET driver, Coil dependent
  - **MCU**, optional for CEC or low power standby
  - **3V3**, Generic Buck or LDO

- **Advantage over High Integration Solution**
  - Coil size dominates the space in TX design, not silicon size !!
  - Flexible design rather then high integration.
  - Power Stage can be reused while different topology is used (A1/A5/A10/A11/A6)
  - Optional MCU, can be cost and performance optimization
  - In case of silicon damage, easy to repair

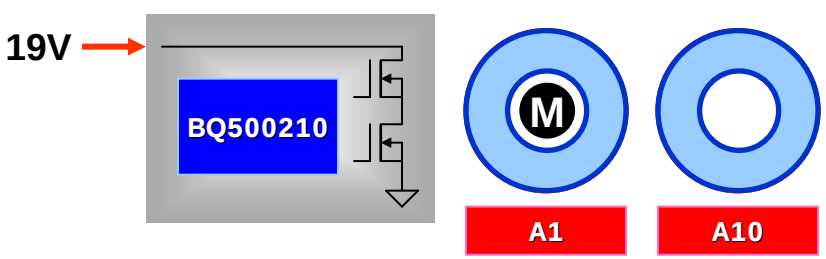
BQ500210
A1 Coil, 53x53mm
Define by WPC

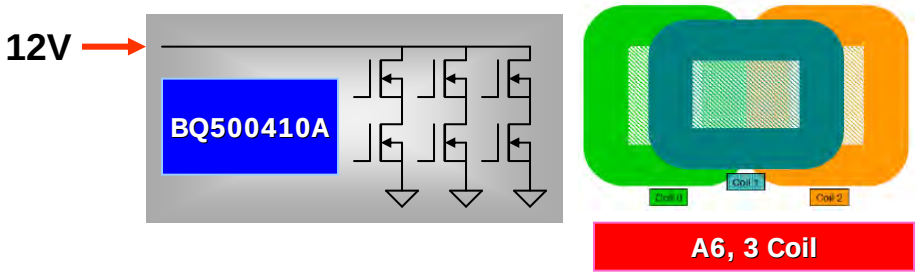
TX, bq50k Family

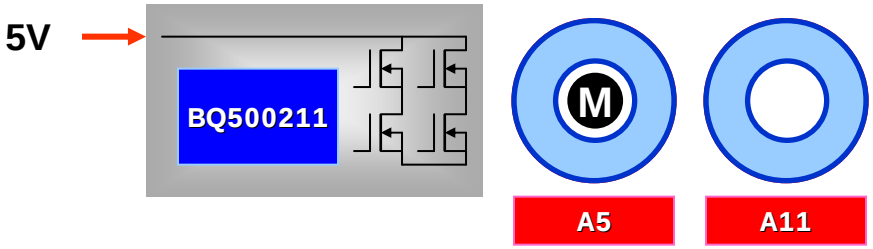
Device	Function	WPC Version support	Output Power	Input Voltage	Rx Positioning on TX Pad	PMOD / FOD support	Dynamic Power Limit Support (DPL)	EVM / Schematic availability	Availability
bq500110	Gen-1 19V/1-Bay WTPX controller	WPC1.0	5W	19V	Guided A1	PMOD	NO	Web-orderable	**RELEASED 2010**
bq500210	Gen-2 19V/1-Bay WTPX controller	WPC1.0	5W	19V	Guided A1/A10	PMOD	NO	Web-orderable	**RELEASED 2011**
FUTURE									
bq500211	**5V**/1-Bay WTPX controller	WPC1.0	5W	**5V**	Guided A5/A11	NO	**Yes**	Internal Sampling	**RELEASED 2Q 2012**
bq500410A	**Free Positioning** WPTX controller	WPC1.1 Ready	5W	12V	**Free Positioning**	FOD/ PMOD	NO	Internal Sampling	**RELEASE 4Q 2012**
bq500211A	5V/1-Bay WPTx Controller	WPC1.1	5W	5V	Guided A5/A11	FOD/ PMOD	Yes	Internal Sampling	**RELEASE 4Q 2012**
bq500414Q	WPTX controller for **Automotive**	WPC1.1	5W	12V	Guided	FOD	NA	NO	**CY13**

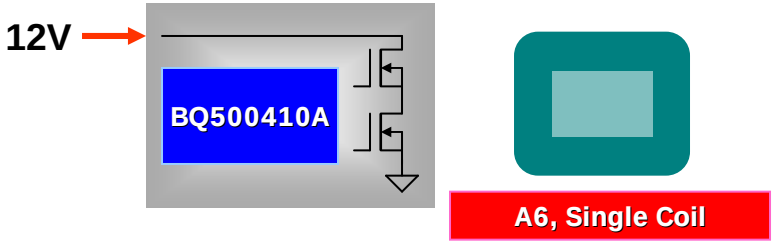
Note: All the current WPTX transmitters are 1-bay (Single Rx charging at a time) support.

WPC TX Selection

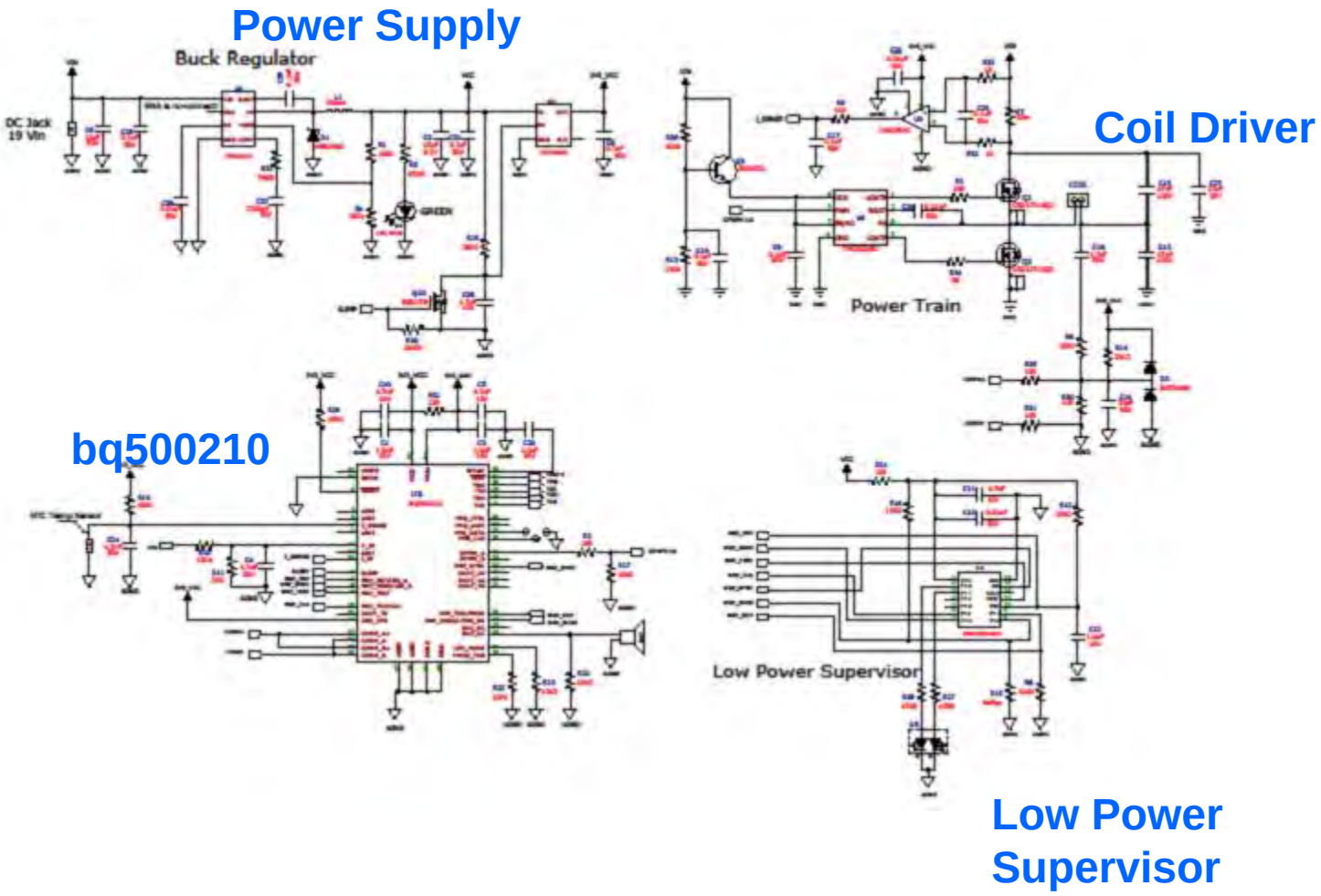




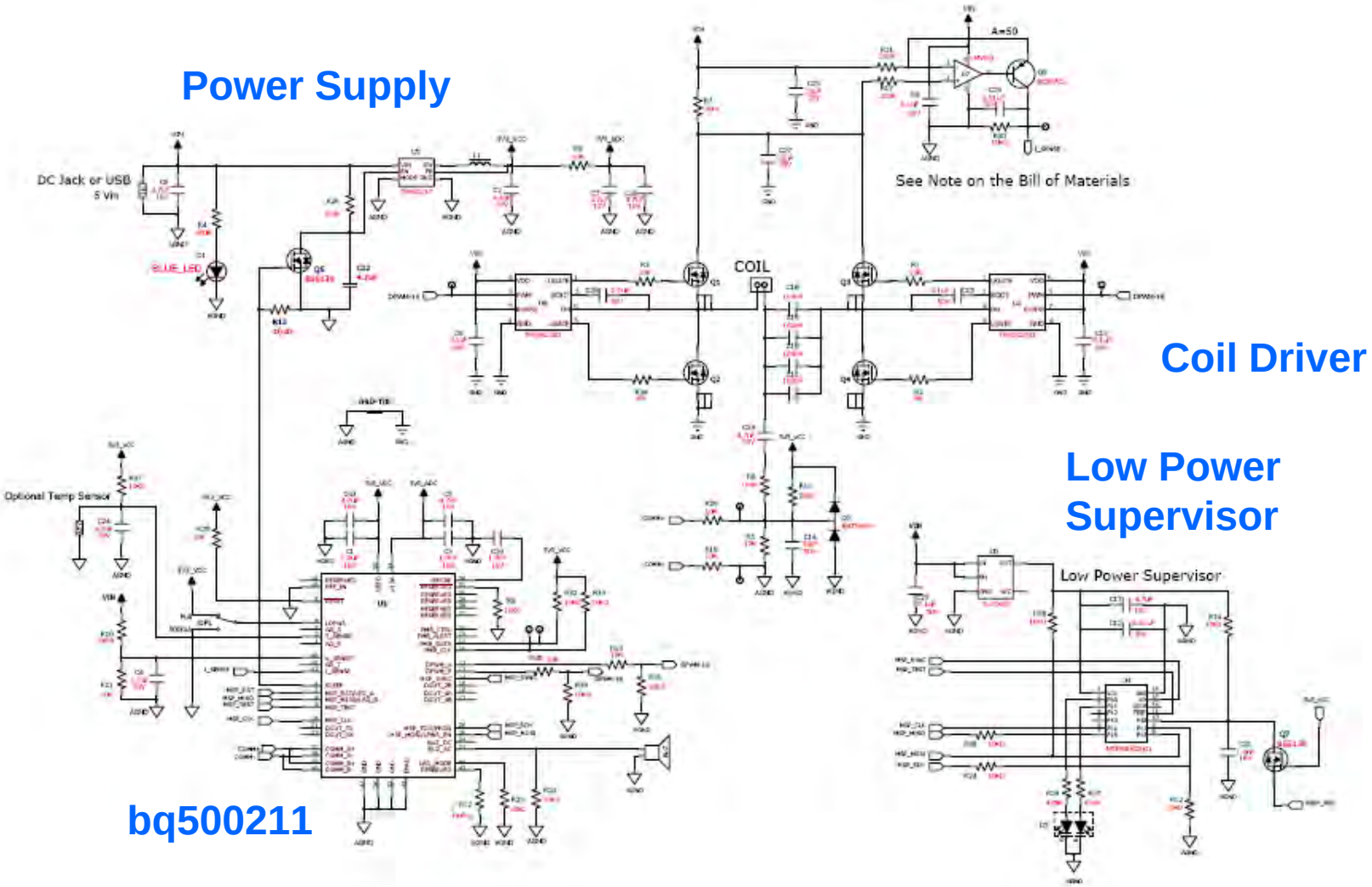




BQ500210 Schematic



BQ500211 Schematic



bq500211 – Dynamic Power Limit™

Operating from USB Port or Low Input Power Adapter

- For Qi Certification and WPC Compliance, Transmitter must be certified with a ~7W Transmitter

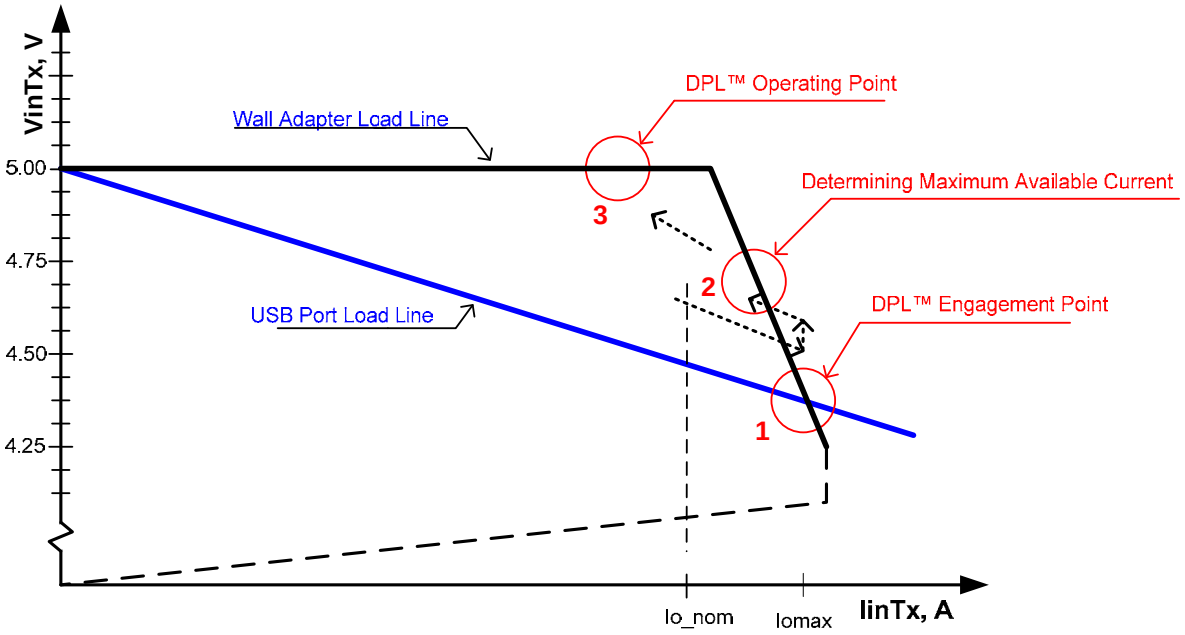
- A 5V Transmitter will allow operation from other popular adapters
  - USB Ports
  - Low Power Adapters (<7W)

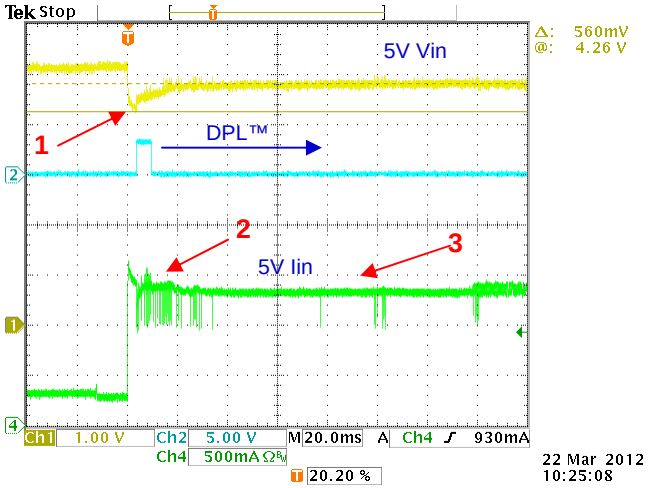
- Latest WPC Spec recognizes operation from lower power ports
  - Need to notify user that “Full 5W Capability” is not available

- bq500211 features “Dynamic Power Limit™”
  - Limits output current to ensure Input Supply not pulled down
  - Optional 500mA Current Limit, limits peak o/p current for USB compliant systems
  - Activates LED to indicate ‘Non WPC/Restricted Power’ operation

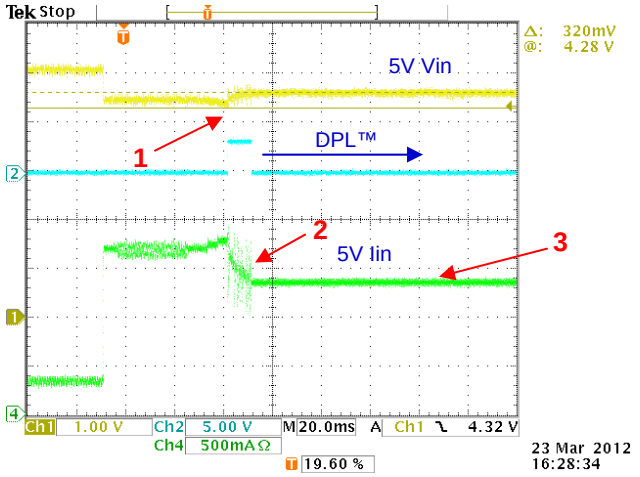
- Some Receivers may not be able to take advantage of DPL™
  - ie, Rx send EPT due to not enough power, or no ‘Input DPM on Charger’

Dynamic Power Limiting™





Travel Adapter– 1A



Notebook USB Port

- DPL is triggered by VIN drop to 4.25V (1)
- The Input Voltage is at ~90% of trigger point is measured and memorized. RX commands for lower operating frequency are ignored. (2)
- The inner feedback loop starts regulating Vin operating point within ~+/-100mV. TX LED turns flushing orange. (3)

Impact of ‘Optional’ Supervisor

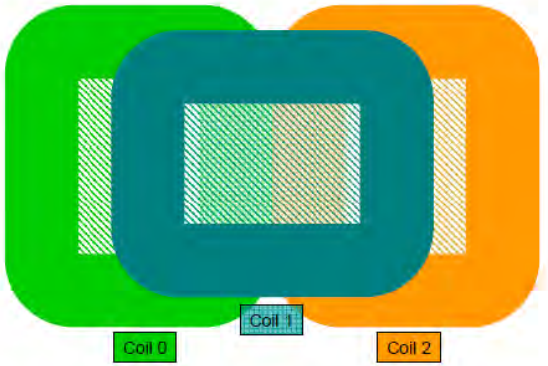
- Gen2 Solution uses lowest cost MSP430 to implement Optional Low Power Mode
- MSP430 is active for ~400ms, vs ~60ms.
- MSP430 :
  - Maintains LED status when bq500xxx device s powered off
  - Serves as non-volatile memory for bq500xxx device

	no MSP430	w/ MSP430 & LED	w/ MSP430 & no LED
~Iq (mA)	15	4.7	3
~Pq (mW)	300	90	60
Iq Rxom (mA)	40	36	36

- bq50k device automatically programs ‘blank MSP430’ the first time power is applied
  - On subsequent power cycles, the bq500xxx device stores off state and timing info before entering sleep mode, ie, Ensures Rx has not been changed
  - bq500xxx device puts itself to sleep and comes out of sleep ~400ms later (due to external Cap) reading back data stored in MSP430

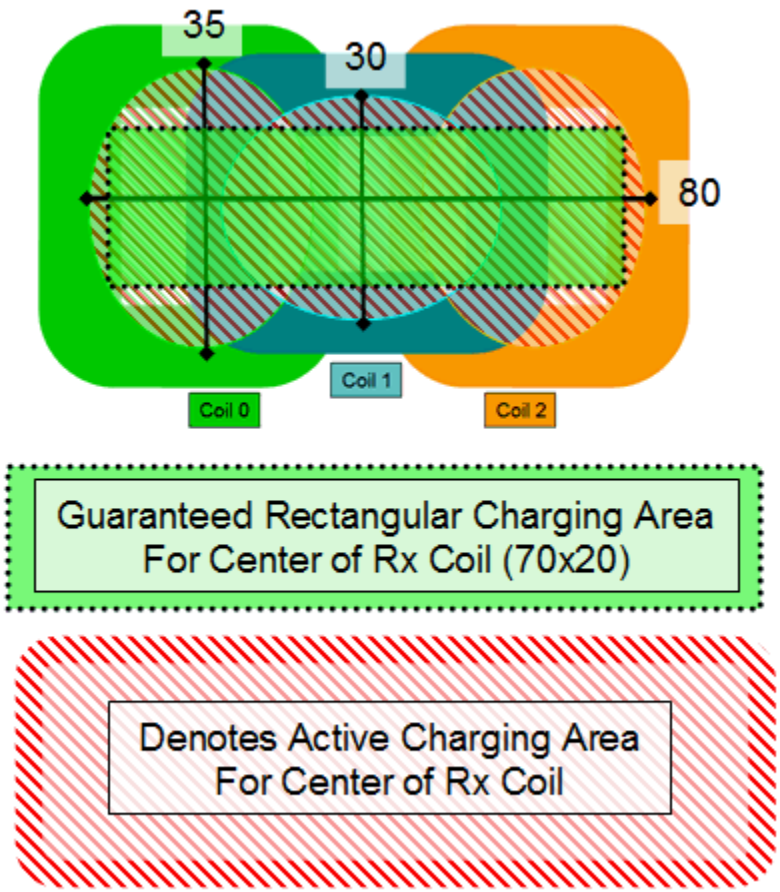
bq500410A – 3 Coil Transmitter

- **WPC A6 (RFP, Rectangle Free Position) significantly improves Charging Area for WPC Compliance**
  - From A1 18x18mm to > 70x20mm
  - Extend definition to “At least one Primary Coil”

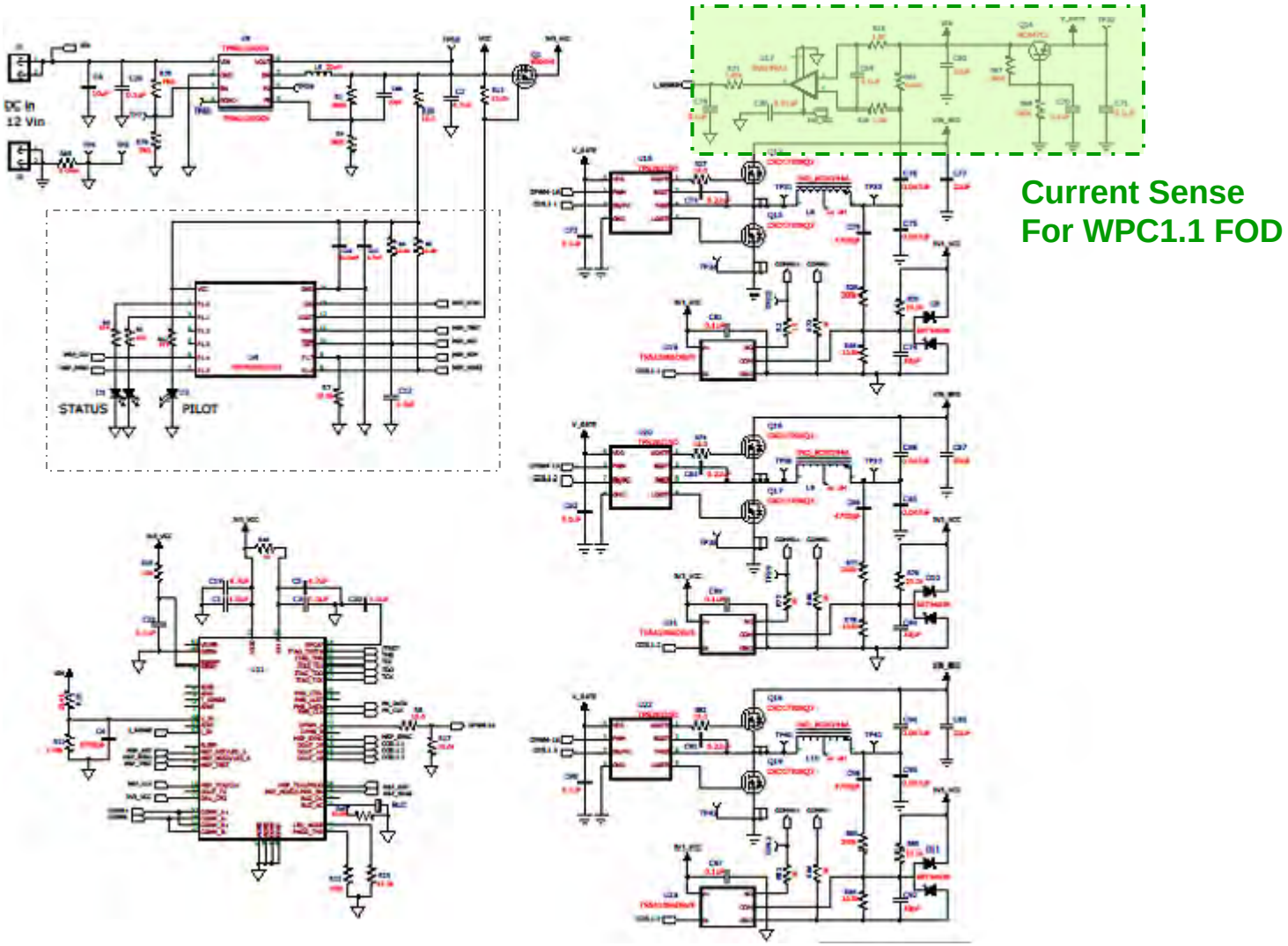


- **Key Specs**
  - 12V Input Voltage
  - A1 Power Transfer Methodology,
    - Half Bridge
    - 120KHz to 205KHz frequency range
    - 175KHz +/-5KHz Digital Ping to initiate Transfer
    - Same Shielding
- **Drives one coil at a time, Enables Efficiencies > 70%**
- **Robust Drive methodology addresses potential issues w/ large Transmitter coils (several patents pending)**
  - Rx Overvoltage, Controlled coupling for WPC1.1, Protection from Friendly metal

bq500410A – Charging Area for WPC

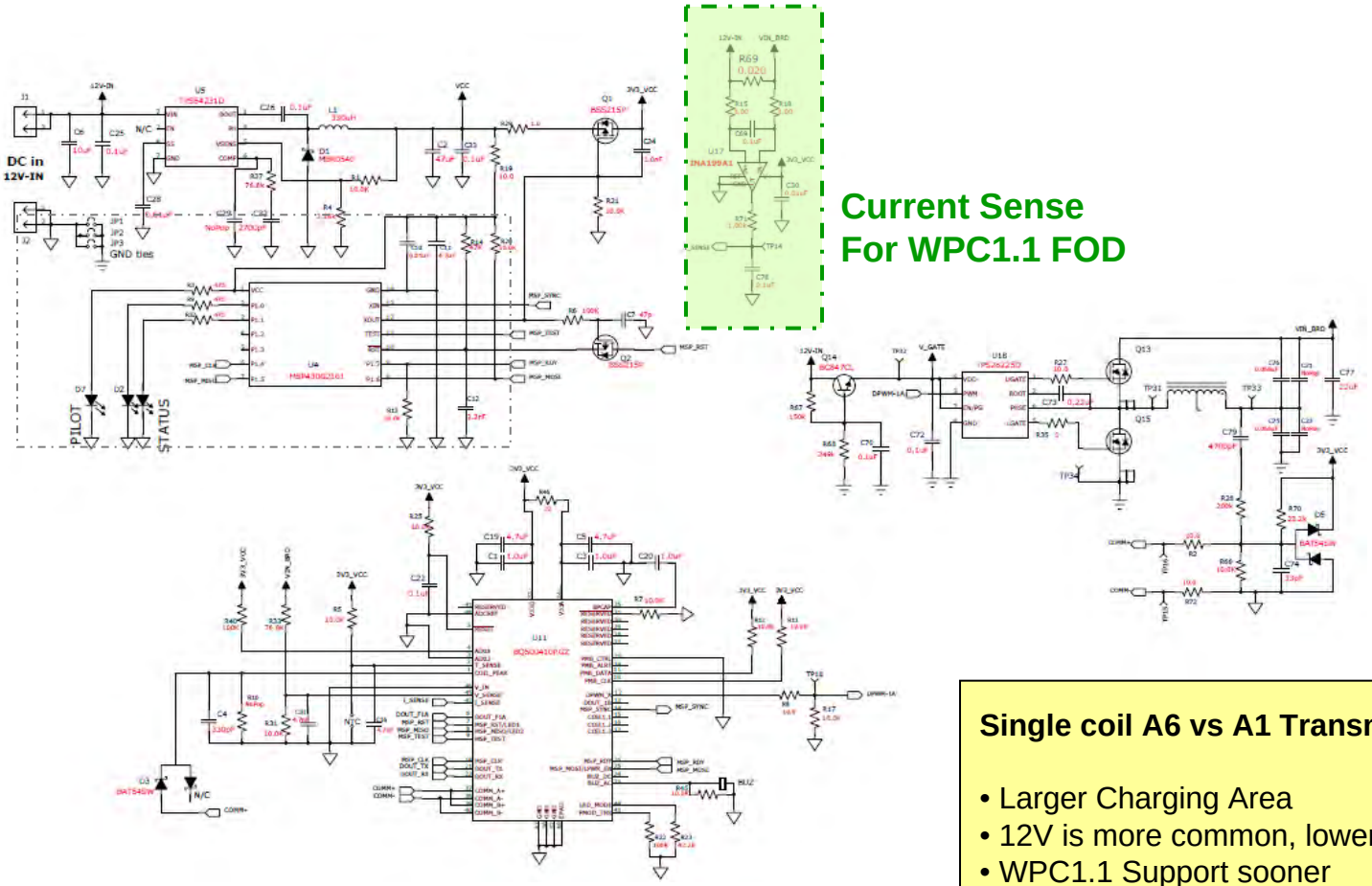


bq500410A – Schematic



Current Sense For WPC1.1 FOD

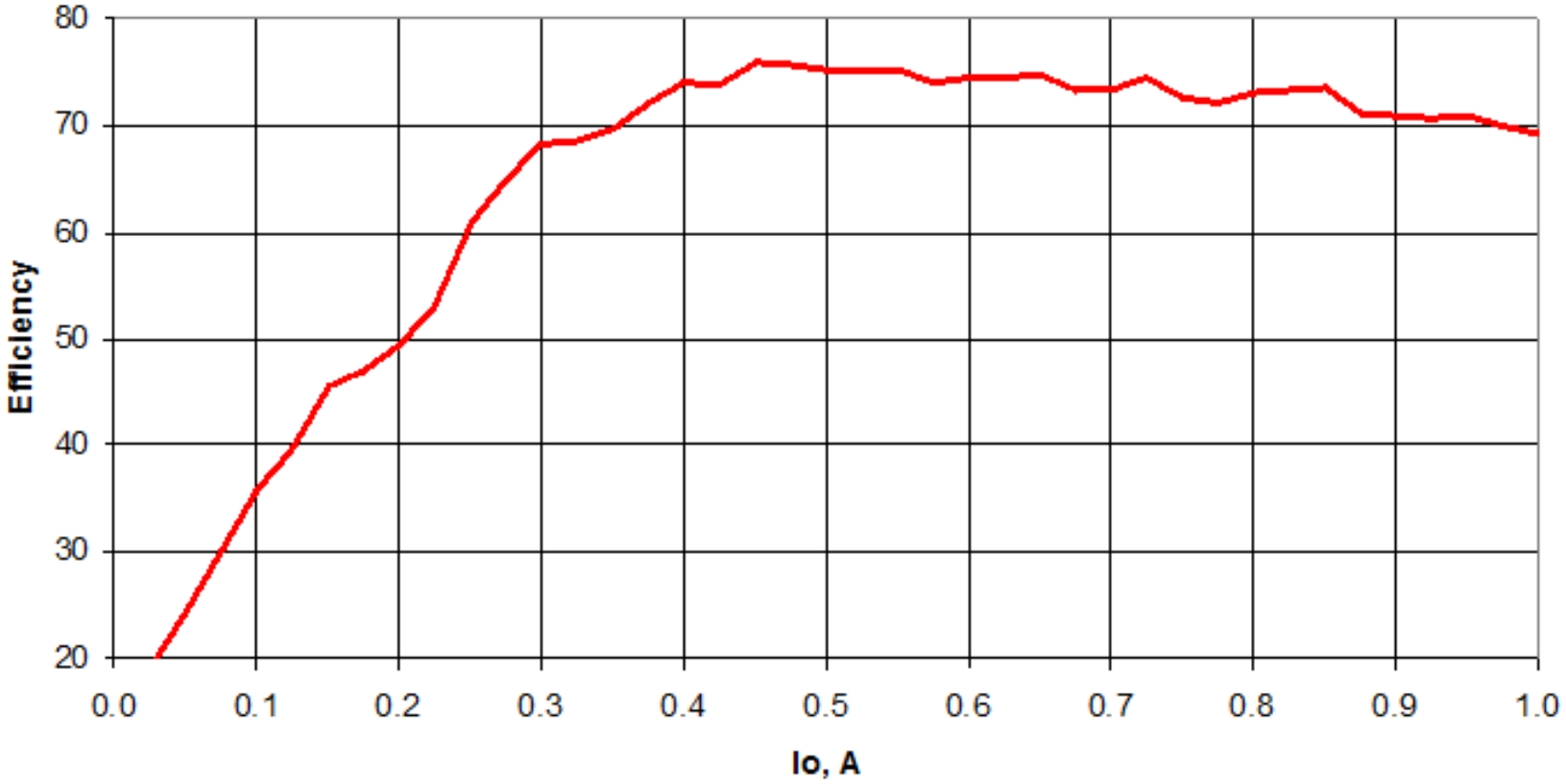
bq500410A – Schematic (Single Coil)



Single coil A6 vs A1 Transmitter

- Larger Charging Area
- 12V is more common, lower cost adapter
- WPC1.1 Support sooner
- DC/DC can be lower cost
- Lower voltage FETs for lower cost maybe

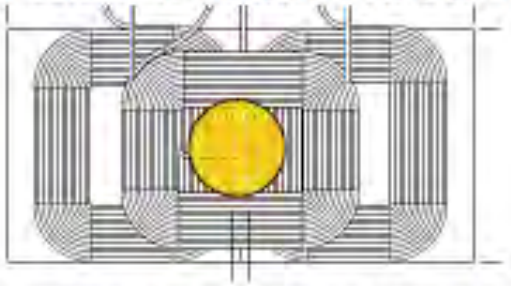
bq500410A – Efficiency



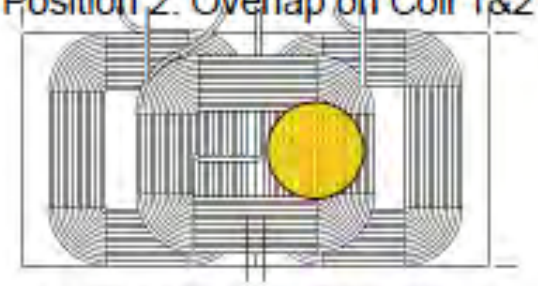
RFP Efficiency vs Placement

	Pin	Vin	Iin	Vout	Iout	Pout	Efficiency
Config A							
Position 1	5.92	12.0	0.49	4.2	1.03	4.33	73%
Position 2	6.40	12.0	0.53	4.2	1.02	4.25	66%
Position 3	6.28	12.0	0.52	4.2	1.01	4.20	67%
Config B							
Position 1	6.52	12.0	0.54	6.7	0.76	5.13	79%
Position 2	7.16	12.0	0.60	6.8	0.78	5.33	74%
Position 3	6.84	12.0	0.57	6.8	0.75	5.14	75%
Config C							
Position 1	2.65	12.0	0.22	4.2	0.43	1.79	68%
Position 2	2.75	12.0	0.23	4.2	0.42	1.76	64%
Position 3	2.74	12.0	0.23	4.1	0.42	1.73	63%
Config D							
Position 1	2.30	12.0	0.19	7.4	0.10	0.73	31%
Position 2	3.37	12.0	0.28	7.6	0.10	0.77	23%
Position 3	3.60	12.0	0.30	7.3	0.10	0.72	20%

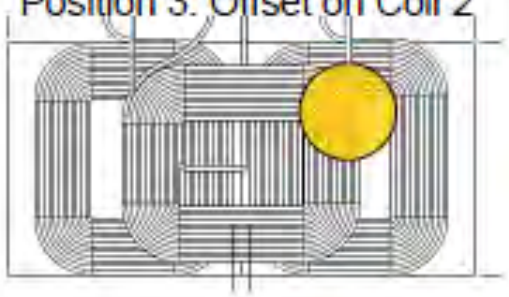
Position 1: Centered on Coil 1



Position 2: Overlap on Coil 1&2

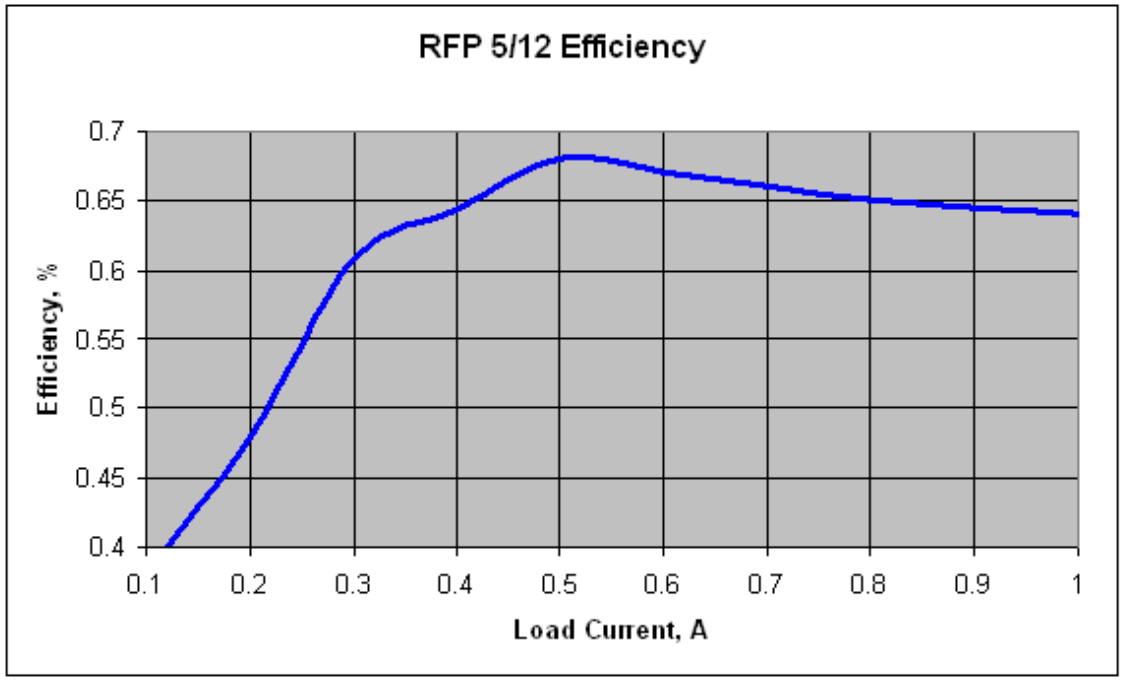


Position 3: Offset on Coil 2



bq500410A – RFP Efficiency w/ 5Vin Boost

- **By using Boost Converter for 5Vin to 12V, (TPS61085), high efficiency is still possible**
- **Efficiencies higher than other WPC Free Positioning approaches (ie B1)**



bq500410A – Advantages Summary

- **Excellent Free Positioning Area: >20mm x 70mm**
- **Drives just one coil at a time (A1 drive) – simpler circuit and >70% efficiency**
- **No Holes in Charging Area**
- **No Magnet**
- **Potential to build 5Vinput version**
  - Today: using 5V to 12V Boost, while still >65% Efficiency
- **WPC approved as new Transmitter type – A6**
- **Release Nov 2012**

TX Design Consideration

- **Design from Silicon**
  - TI EVM had pass QI certification, Suggest to follow reference design for the first build
  - 4 layer PCB design is required
  - Use C0G type for the resonant capacitor
  - Start with TI qualified coil vendor
  - Pass QI certification by your own (need to have WPC membership)
  - Risk on changing component, result
    - C0G capacitor, reduce TX/RX sensitivity, effective z distance, characteristics change across temperature
    - FET, FOD loss calibration required
    - Coil, WPC compliance, and Q factor
- **Design from Module**
  - Contact TI ODM partner with WPC membership
  - Using QI certificated TX/RX module from TI ODM
- **Purchase Finish Good Product**
  - Contact TI ODM partner with WPC membership

Summary - WPS

- bq50K → WPS TX Family
- bq51K → WPS RX Family

- WPC Website → http://www.wirelesspowerconsortium.com/
- TI bqTesla → http://www.ti.com/bqTesla

- TI offer WPC certificated EVM and reference design to speed up to design, please contact TI sales for detail
- Contact TI for recommended ODM and qualified critical component vendors

- Asia Contact : Silvan Ho, silvan_ho@ti.com

Questions …….

AVID Debug Tool

- **AVID,** www.avid-tech.com/wirelesspower.
- **The Qi Sniffer** is a USB device that can be placed near a Qi compliant wireless charging system (TX and RX pair) and used to capture the wireless communication packets and other system operating information.

- **The Qi Receiver Simulator** is a device that can be placed on a Qi wireless charging transmitter and used to test the transmitter's operation and performance.
- Please review the attached spec sheets as well as our website at www.avid-tech.com/wirelesspower.

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