Power solutions for Wireless Charging

June 2018

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MPS®
Simple, Easy Solutions™

rev 20170706

Outline

- **QI standard for Power transfer**
  - Reference designs for extended power profile
  - Power transfer phases
  - Communication between TX and RX
- **MPS Power solutions**
  - Tx Side
  - Rx Side

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- **MPS Power solutions**
  - o Tx Side
  - o Rx Side

Introduction of Qi Standard

- Current version: 1.2.4
- Power levels:
  - Baseline Power Profile: 5 W
  - Extended Power Profile: 15 W (**FOD must be included**)
- Operation frequency: in the 87…205 kHz range.
- Two types:
  - **Type A**
    - **Activates a single Primary Coil** at a time.
    - Employs a single Primary Cell that coincides with the activated Coil.
    - Includes means to realize proper alignment of the Primary Coil and Secondary Coil.
  - **Type B**
    - **Activates one or more Primary Coils** from the array.

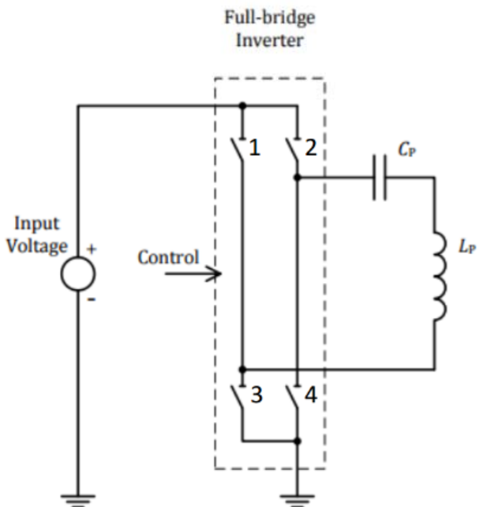
	Activated Primary Coil Simultaneously	Inverter	Alignment
Type A	Single	Several, lower power	Alignment aid required
Type B	Single or several	Single, higher power	Free-positioning

Reference Design (15 W)

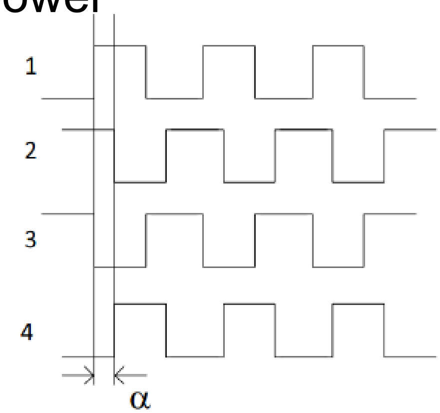
- Listed in part 4 of Qi standard
- Five reference designs are given in Qi:
    - MP-A1
    - MP-A2
    - MP-A3
    - MP-A4
    - MP-A5

Topologies

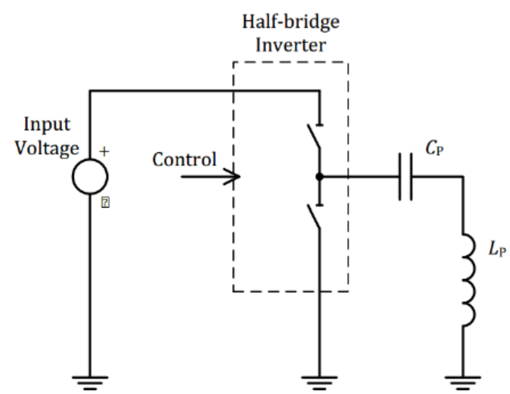
Full Bridge



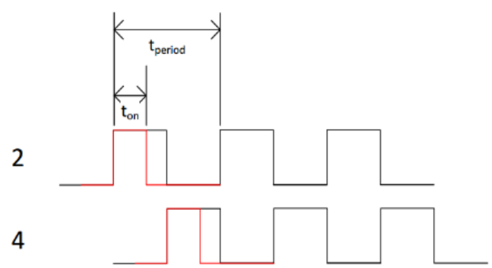
Phase shift to control power



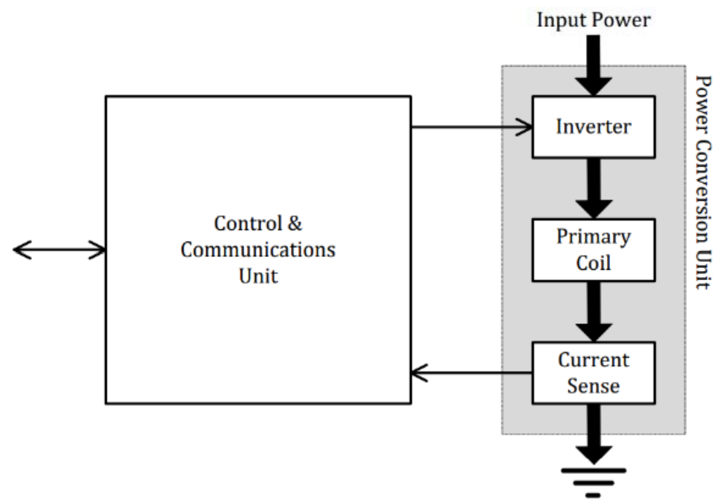
Half Bridge



Duty cycle to control power



Function Blocks



Communication signal is on top of the coils current.

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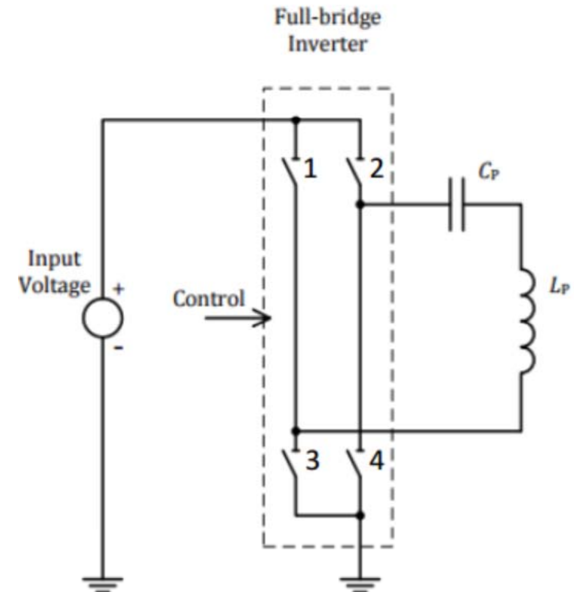
Reference Design MP-A1

- Control method for power transfer:
  - o **Operating frequency**
  - o **Duty cycle for half bridge**, **or phase shift for full bridge**
- Specifications:
  - o Operating frequency: 110 kHz - 205 kHz
  - o Duty cycle for half bridge: 10% - 50%
  - o Phase shift for full bridge: 0˚ to 135˚
  - o Vin = 19 V

Electrical Diagram



Control Methodologies

Frequency	Mode	Phase or duty cycle
205 kHz	HB	10% to 50%
160 – 205 kHz	HB	50%
160 kHz	FB	0˚ to 135˚
100 – 160 kHz	FB	0˚

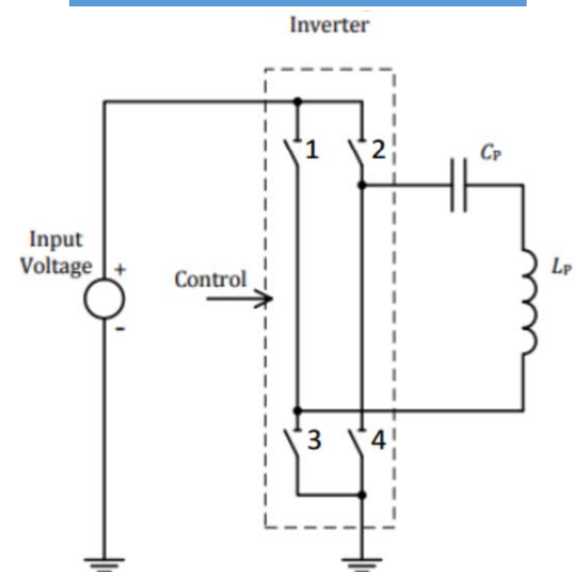
Reference Design MP-A2

- Control method for power transfer:
  - o **Operating frequency**
  - o **Duty cycle**
- Specifications:
  - o Operating frequency: 110 kHz - 145 kHz
  - o Duty cycle of full bridge: 5% - 50%
  - o Vin = 12 V

Control Methodologies

Frequency	Mode	Duty Cycle
110 – 145 kHz	FB	40% - 50%
145 kHz	FB	5% - 50%

Electrical Diagram



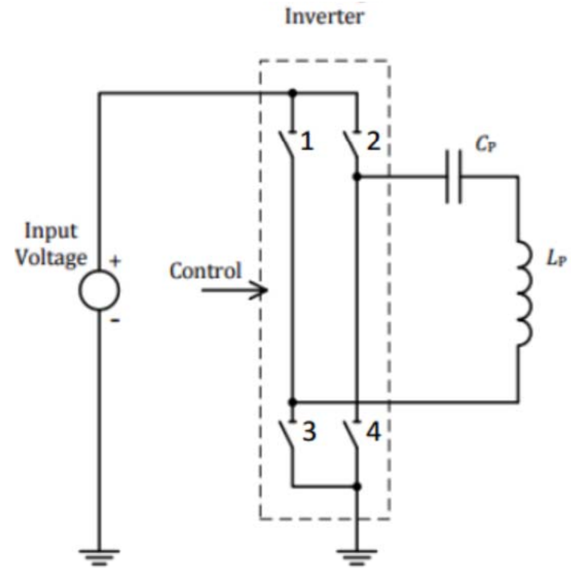
Reference Design MP-A3

- Control method for power transfer:
  - o **Operating frequency**
  - o **Duty cycle**
  - o **Input voltage**
- Specifications:
  - o Operating frequency: 110 kHz - 205 kHz
  - o Duty cycle of full bridge: 5% - 50%
  - o Input voltage: 2.5 – 11.5 V

Control Methodologies

Frequency	Mode	Duty Cycle
110 – 205 kHz	FB	50%
205 kHz	FB	0% - 50%

Electrical Diagram



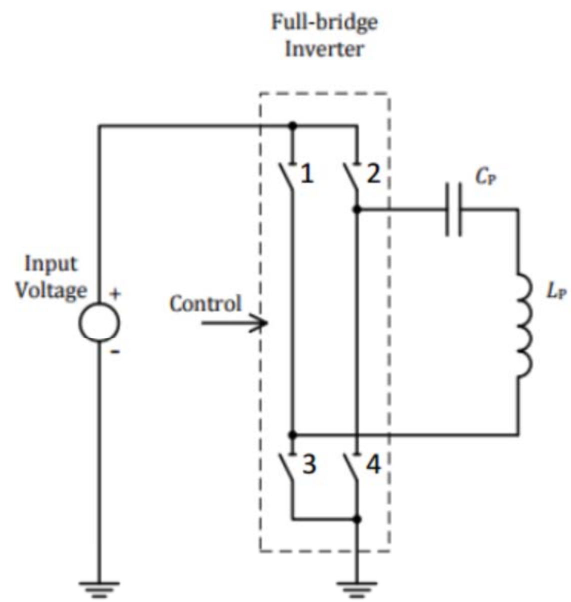
Reference Design MP-A4

- Control method for power transfer:
  - **Operating frequency**
  - **Duty cycle for half bridge, or phase shift for full bridge**
- Specifications:
  - Operating frequency: 110 kHz - 205 kHz
  - Duty cycle of half bridge: 5% - 50%
  - Phase difference of full bridge: 0˚ to 133˚
  - Input voltage: **12 V**

Control Methodologies

Frequency	Mode	Phase or Duty Cycle
105 – 172 kHz	FB	0˚
172 kHz	FB	0˚ to 133˚
172 – 205 kHz	HB	50%
205 kHz	HB	10% - 50%

Electrical Diagram

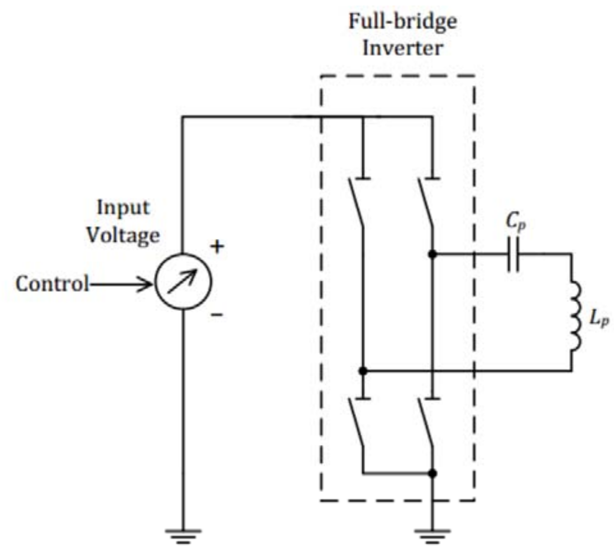


Reference Design MP-A5

- Control method for power transfer:
  - o **Input voltage**
- Specifications:
  - o Operating frequency = 130 kHz
  - o Duty cycle = 50%
  - o Input voltage: 1 – 12 V

Fixed frequency, good for automotive.

Electrical Diagram



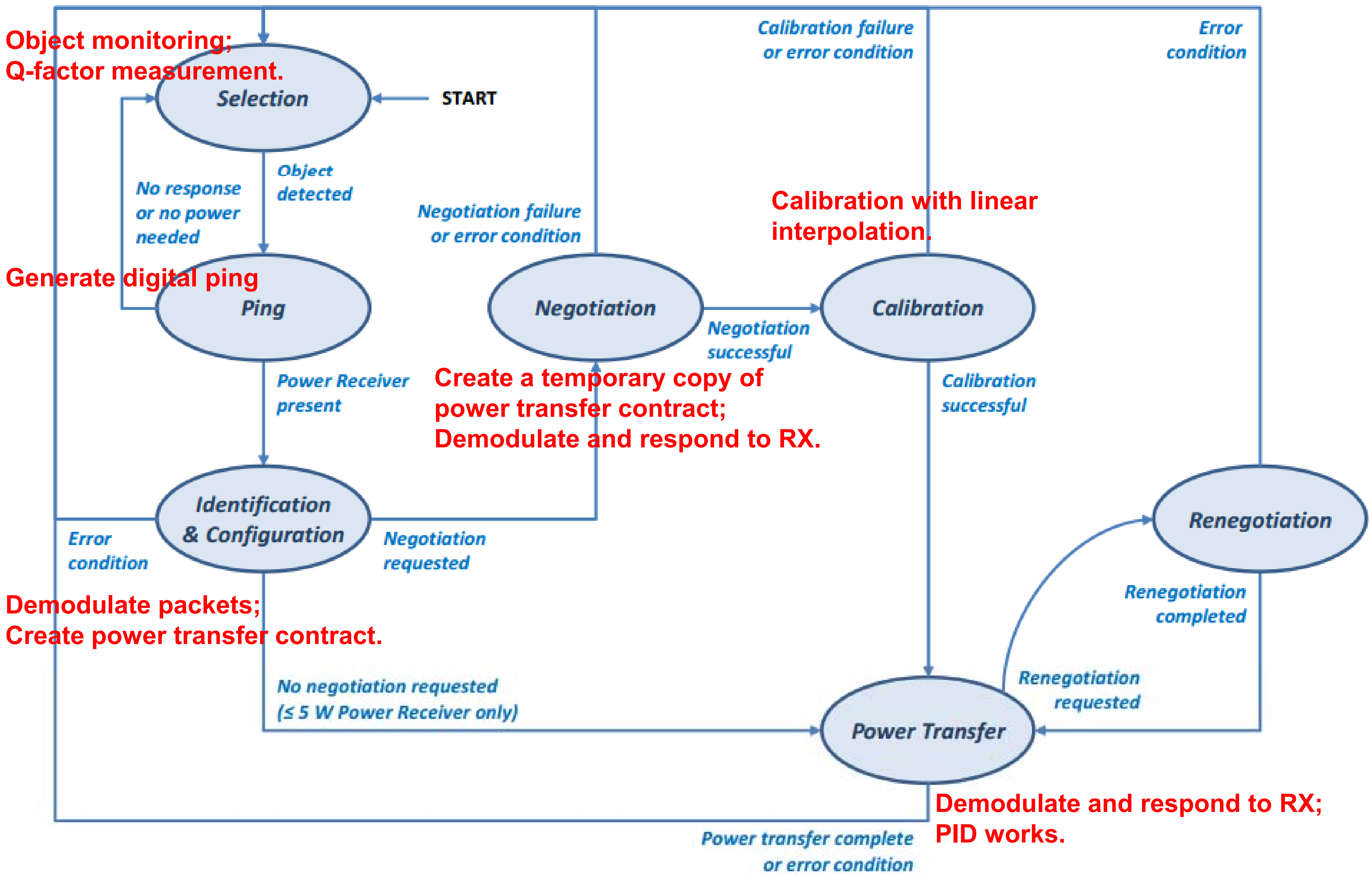
Comparison of Reference Designs (15 W)

	MP-A1	MP-A2	MP-A3	MP-A4	MP-A5
Control Method	Frequency Phase shift Duty cycle	Frequency Duty cycle	Frequency Duty cycle Input voltage	Frequency Phase shift Duty cycle	**Input voltage**
Topology	Full bridge Half bridge	Full bridge	Full bridge Half bridge	Full bridge	**Full bridge**
Sensors	Current	Current	Current Voltage	Current	**Current Voltage**
Vin	19 V	12 V	2.5 – 11.5 V	12 V	**1 – 12 V**
Resonant frequency	100 kHz	100 kHz	100 kHz	100 kHz	**100 kHz**
Operating frequency	110 – 205 kHz	110 – 145 kHz	110 – 205 kHz	110 – 145 kHz	**130 kHz**

Outline

- Investigation of Qi standard 1.2.2
  - Reference designs for extended power profile
  - **Power transfer phases**
  - Communication between TX and RX
- MPS products
  - MP-A5 Tx Side
  - Rx Side

Power Transfer Phases



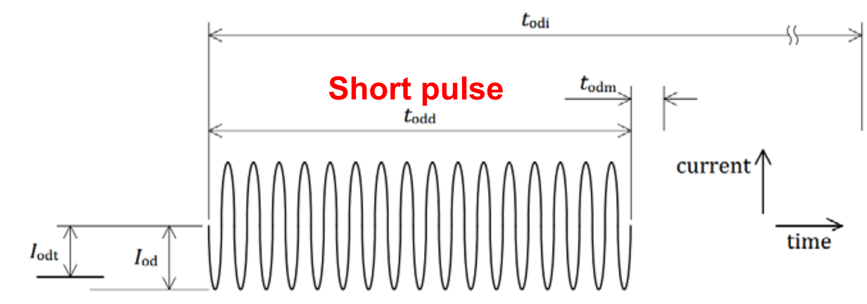
Selection Phase

- **Two tasks for TX:**
  - Monitor the Interface Surface for the placement and removal of objects;
  - Measure the quality factor (Q-factor) for foreign object detection (FOD)
- **Two methods to monitor the objects:**
  - Resonance shift
  - Capacitance change
- **Measurement of Q-factor**
  - After object is detected, TX measures the Q factor of TX coil
- ***Optional functions:***
  - Differentiate between Power Receiver and Foreign Objects
  - Locate the objects

Selection Phase: Object Detection

Resonance Shift

- TX applies a very short pulse to TX coil at resonance frequency (100 kHz)
- Highest current I_{od} occurs if resonance frequency is not changed (no object)
- Compare I_{od} with threshold values to determine whether an object is present

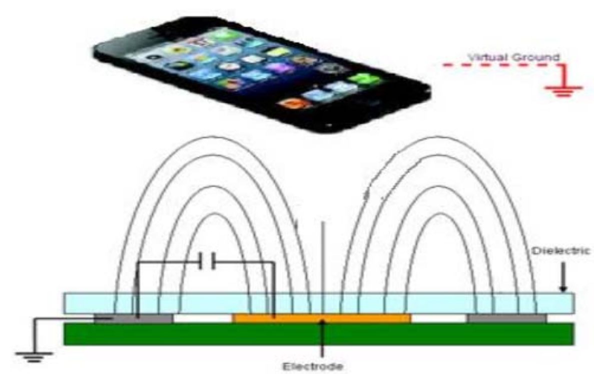


Parameter	Symbol	Value	Unit
Object detection interval	t_{odi}	500	ms
Object detection duration	t_{odd}	70	µs
Object detection measurement	t_{odm}	19.5	µs

Capacitance Change

- Add an electrode on or near the Interface Surface and detect the change of capacitance
- The electrode should not be placed above TX coil (influence FOD)
- Benefit: power consumption is much lower than resonance shift

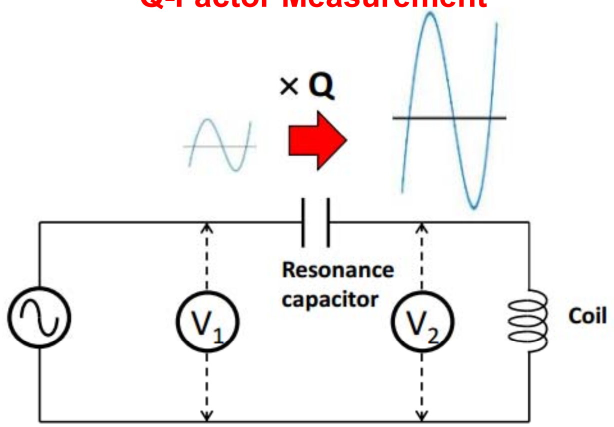
Freescale Solution



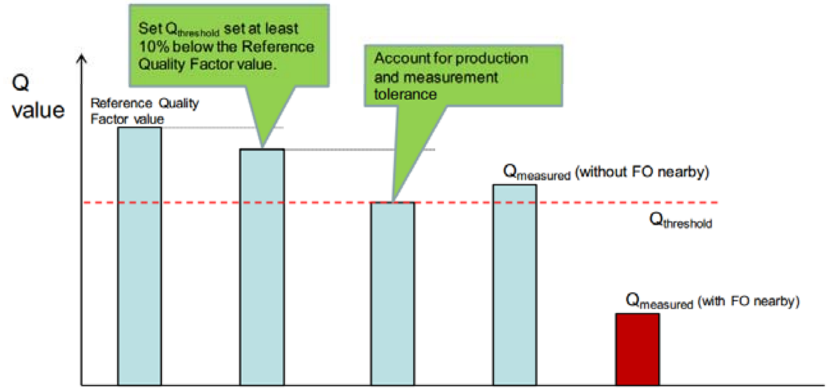
Selection Phase FOD: Q-Factor Measurement

- **TX actions in selection phase:**
  - Directly after RX is placed on the TX, TX measures the Q-factor $Q_{measured}$ of its TX Coil;
  - The TX uses a sufficiently small amount of power, such that the RX does not wake up;
- **TX actions in negotiation phase:**
  - TX receives FOD Status Packet (0x22) and uses the reported reference Q factor value to determine an appreciate FOD threshold $Q_{threshold}$;
  - FOD Status Packet contains information of the RX influence on $Q_{measured}$, which is used for calibration.

Q-Factor Measurement



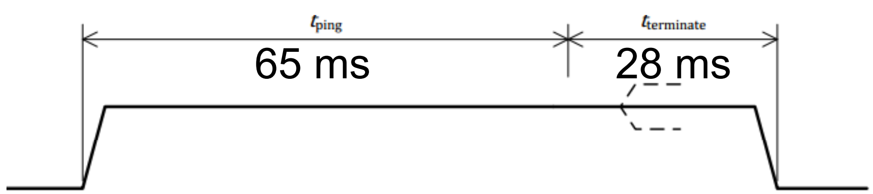
Threshold of Q-Factor



Ping Phase

- TX executes a Digital Ping, at the operating point defined for particular reference design
- Wait for response from RX
  - o If TX receives Signal Strength Packet from RX, proceed to identification & configuration phase
  - o If TX receives other packet, in particular End Power Transfer Packet, TX should remove the power signal within $t_{terminate}$ (28ms) after the end of the packet
  - o If TX does not detect the start of a packet in the time window t_{ping} (65ms) after primary cell current amplitude reaches 50% of the stable level, remove the power signal within $t_{terminate}$ (28ms)
  - o If TX does not proceed to identification & configuration phase, go to selection phase.

Digital Ping



Identification & Configuration Phase

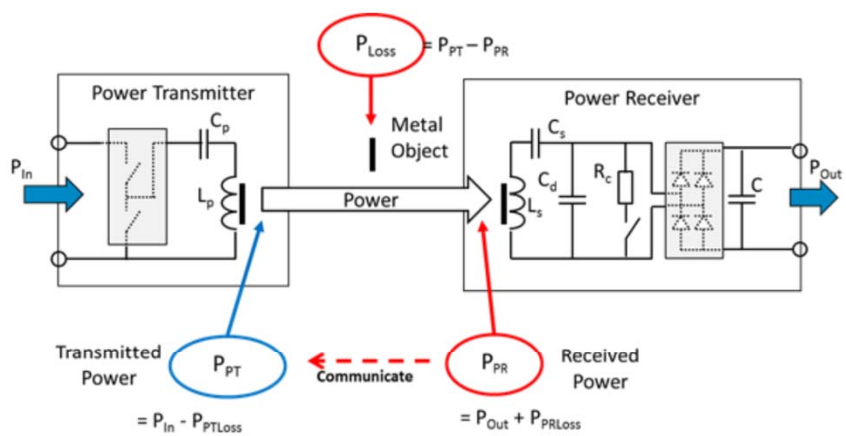
- TX identifies the RX and collect configuration information
- TX will receive following packet from RX
  - An **identification packet**
  - An **extended identification packet** (if Ext bit = 1 of identification packet)
  - Up to 7 **optional configuration packet** (Power control hold-off packet, Proprietary packet, reserved packet)
  - A **configuration packet**
- If TX received all packets in a sequence, **TX creates a Power Transfer Contract**:
  - FOD extensions not supported: proceed to power transfer phase
  - FOD extensions supported:
    - Neg bit of configuration packet = 0: proceed to power transfer phase
    - Neg bit of configuration packet = 1: TX sends an Acknowledge response and procceds to negotiation phase

Negotiation Phase

- TX receives a series of Packets that contain requests to update the Power Transfer Contract
- In response to each Packet, the Power Transmitter shall send
  - A Response to indicate whether it grants the request, denies the request, or does not recognize the request, or
  - a data Packet that contains the requested information
- Prior to receiving the requests to update the Power Transfer Contract, the TX shall create a temporary copy of the Power Transfer Contract. The TX shall use this temporary copy to store updated parameters until successful completion of the negotiation phase

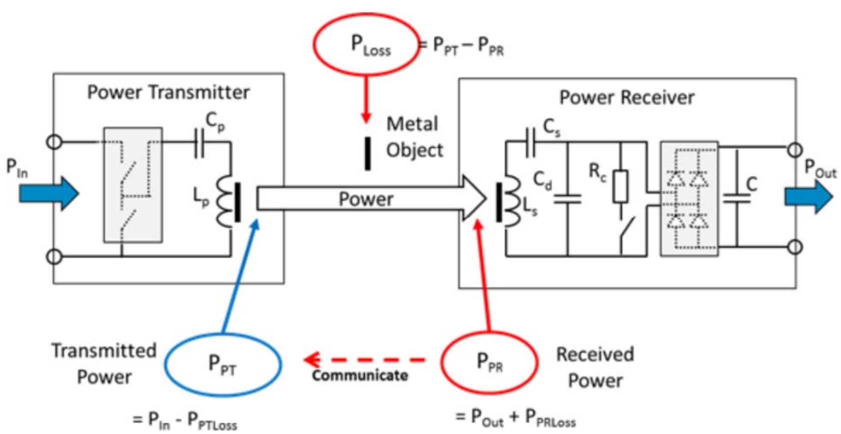
Calibration Phase: FOD Based on Power Loss

- The power loss P_{loss} is defined as the difference between the Transmitted Power P_{PT} and the Received Power P_{PR}
- P_{loss} provides the power absorption in Foreign Objects
- $P_{PT} = P_{in} – P_{PTloss}$
  - o P_{in} is the input power
  - o P_{PTloss} is the power dissipated on the primary side
- $P_{PR} = P_{out} + P_{PRloss}$
  - o P_{out} is the output power
  - o P_{PRloss} is the power dissipated on the secondary side
- $P_{PT} = P_{PR}$ when there is no foreign objects



Calibration Phase: FOD Based on Power Loss

- However, P_{PT} and P_{PR} cannot be measured directly. Therefore, PPT and PPR are calibrated from P_{in} and P_{out} in calibration phase.
- The calibration should ideally be carried out at many power levels between the lowest power and the power that RX expects. Since this is impractical, there is a compromise: TX and RX determine P_{PT} and P_{PR} at two load conditions: a "light" load and a "connected" load.
    - o "Light" load: RX shall limit its Received Power to at most 10% of its Maximum Power.
    - o "Connected" load: close the maximum expected output power.
- TX can calibrate P_{PT} using linear interpolation, or RX can calibrate P_{PR}.



Example: Calibrated P_{PT}

$$P_{\text{calibrated}} = a \cdot P_{\text{transmitted}} + b.$$

$$a = \frac{P_{\text{received}}^{(\text{connected})} - P_{\text{received}}^{(\text{light})}}{P_{\text{transmitted}}^{(\text{connected})} - P_{\text{transmitted}}^{(\text{light})}}$$

$$b = \frac{P_{\text{transmitted}}^{(\text{connected})} \cdot P_{\text{received}}^{(\text{light})} - P_{\text{received}}^{(\text{connected})} \cdot P_{\text{transmitted}}^{(\text{light})}}{P_{\text{transmitted}}^{(\text{connected})} - P_{\text{transmitted}}^{(\text{light})}}$$

$P_{transmitted}$: input power P_{in}
$P_{received}$: output power P_{out}

Power Transfer Phase

- **TX controls the power transfer to RX, inresponse to control data that it receives from the latter.**
- TX shall receive zero or more of the following Packets:
  - o Control Error Packet
    - Upon receiving a Control Error Value, TX shall adjust its Operating Point.
    - Prior to making any adjustment, TX shall wait for an interval to enable the Primary Cell current to stabilize again after communications
  - o Received Power Packet
  - o Charge Status Packet
  - o End Power Transfer Packet
  - o Renegotiate Packet
  - o Any Proprietary Packet
  - o Any reserved Packet
- The Power Transmitter shall monitor the parameters contained in the Power Transfer Contract throughout the power transfer phase

Power Transfer Phases

Phases	Phase Description	Basic Tasks of Transmitter
1. Selection	TX monitors the Interface Surface for the placement and removal of objects.	**1.1. Monitors the objects using resonance shift:** Apply a short pulse to TX coil at 100 kHz, and compare measured current with threshold.
		1.2. Measure the quality factor: Apply a small amount of power, measures coil voltage and inverter voltage, and calculate $Q=V_{coil}/V_{inverter}$.
2. Ping	TX executes a digital ping and waits for response from RX.	**2.1. Generate digital Ping:** Apply power signal at the pre-defined operating point .
		2.2. Wait and reacts to the response from RX: Demodulate the response and proceed to next phase; or return to the selection phase
3. Identification and Configuration	TX identifies the RX and collect configuration information.	**3.1. Receive and demodulate the identification packet from RX.**
		3.2. Receive and demodulate the configuration packet from RX.
		3.3. Create a power transfer contract.
		3.4. Determine to enter power transfer phase, negotiation phase, or selection phase.
4. Negotiation (Extended Power Only)	TX receives a series of Packets that contain requests to update the Power Transfer Contract.	**4.1. Create a temporary copy of the Power Transfer Contract:** TX uses this temporary copy to store updated parameters until successful completion of negotiation phase.
		4.2. Demodulate the packets and send response to RX: 1. A response to indicate whether it grants the request, denies the request, or doesn't recognize the request; 2. A data Packet that contains the requested information.
5. Calibration (Extended Power Only)	TX receives information from the RX to improve the power loss method for FOD.	**5.1. Demodulate the 24-bit received power packet:** "Light" load, or "connected" load
		5.2. Do the calibration using linear interpolation.
6. Power Transfer	TX controls the power transfer to RX.	**6.1. Monitor the parameters contained in power transfer contract.**
		6.2. Receive and demodulate packet: a. Control error packet. Action: adjust operating point via PID. b. Received power packet. Action: send ACK response if no FOD, or NAK if FOD. c. Charging status packet d. End power transfer packet. Action: remove power. e. Renegotiation packet. Action: send ACK response and proceed to renegoation phase.
7. Renegotiation	Same as negotiation phase.	

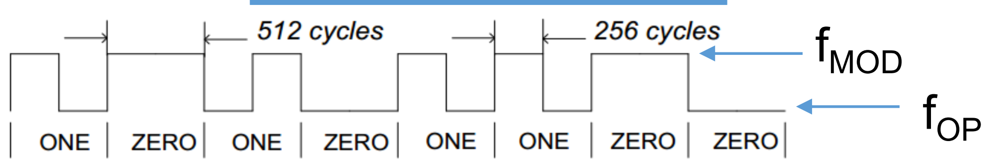
TX to RX Communication

- Frequency shift keying: TX modulates the Operating Frequency of the Power Signal
  - o TX switches its Operating Frequency between the f_{op} in the in the unmodulated state and f_{mod} in the modulated state.
  - o The difference between f_{op} and f_{mod} is determined by Polarity and Depth.
- Bit encoding scheme
  - o ONE: using two transitions in the Power Signal frequency. The first transition shall occur at the start of the bit and the second transition shall occur at 256 cycles into the bit.
  - o ZERO: use a single transition in the Power Signal frequency at the start of the bit.

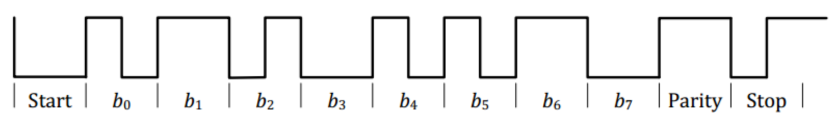
Polarity and Depth

Polarity	Depth	$\frac{1}{f_{mod}} - \frac{1}{f_{op}}$		Unit
		Minimum	Maximum	
positive	3	−282.00	−249.00	ns
positive	2	−157.00	−124.00	ns
positive	1	−94.50	−61.50	ns
positive	0	−63.25	−30.25	ns
negative	0	30.25	63.25	ns
negative	1	61.50	94.50	ns
negative	2	124.00	157.00	ns
negative	3	249.00	282.00	ns

Bit Encoding Scheme



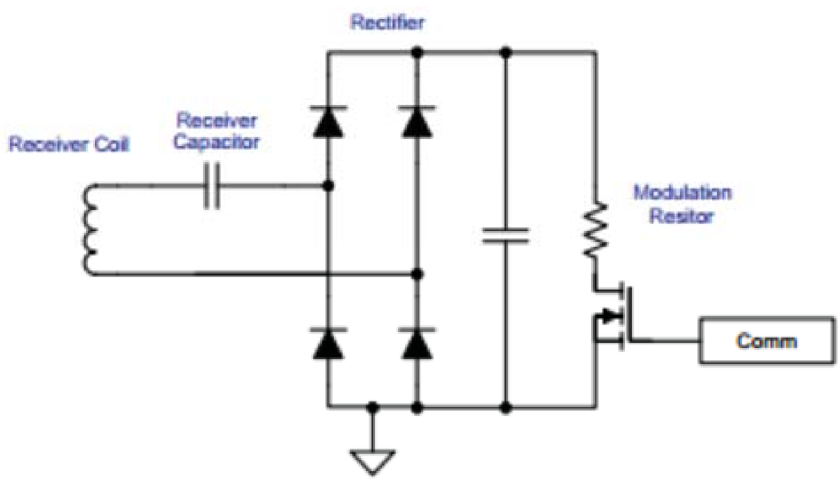
Byte Encoding Scheme



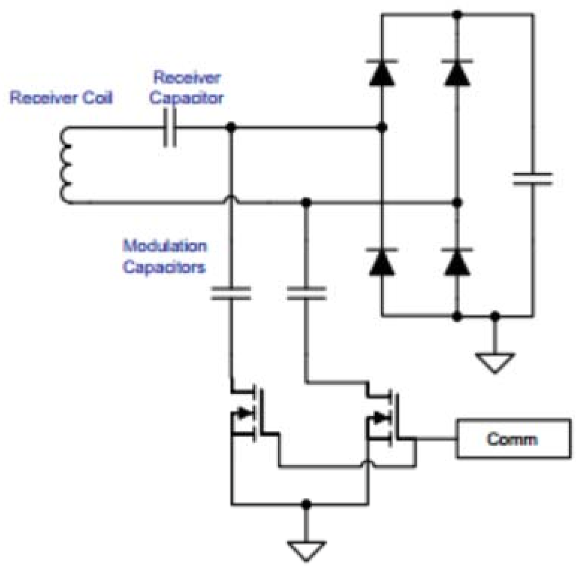
RX to TX Communication: Modulation Methods

- Two ways to send communication signals
  - o Resistive modulation
  - o Capacitive modulation
- When load impedance changes, voltage and current of transmitter coil will change
- The communication signal (2 kHz) is “on top” of the power signal of transmitter coil

Resistive Modulation



Capacitive Modulation

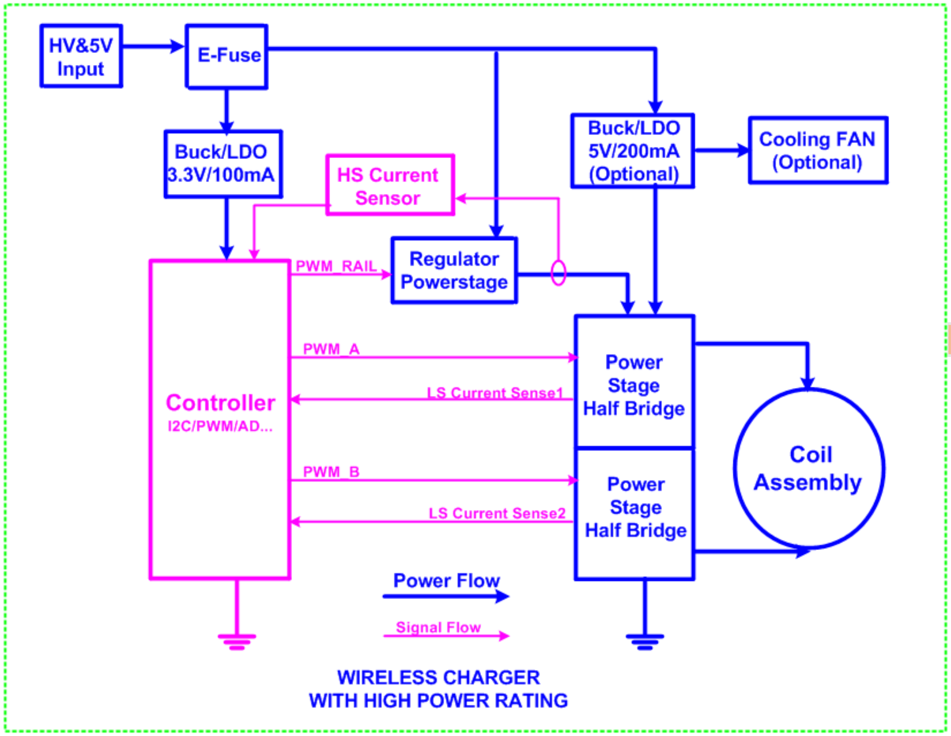


Outline

- QI standard for Power transfer
  - o Reference designs for extended power profile
  - o Power transfer phases
  - o Communication between TX and RX
- **MPS Power solutions**
  - o Tx Side
  - o Rx Side

Power solutions for TX

TX- Power Tree



For Controller Power Supply
- ✓ Bucks MP2269/ MP1652
- ✓ LDO MP2015A

For Half Bridge Inverter
- ✓ DrMos MP86901A/B/C/D
- ✓ HB driver MP1907/1909

For Pre-regulator
- ✓ PWM mode MP86901A/B
- ✓ Analog mode
  - Buck :MP2229/2330/2491C
  - Buck-Boost: MP2980/MP8859

For High side current sensor
- ✓HV sensor MPQ8112

For E-fuse(OVP/OCP)
- ✓MP5016/MP5016H/MP5017

MPS offers total power solutions for transmitter covering all power ratings.

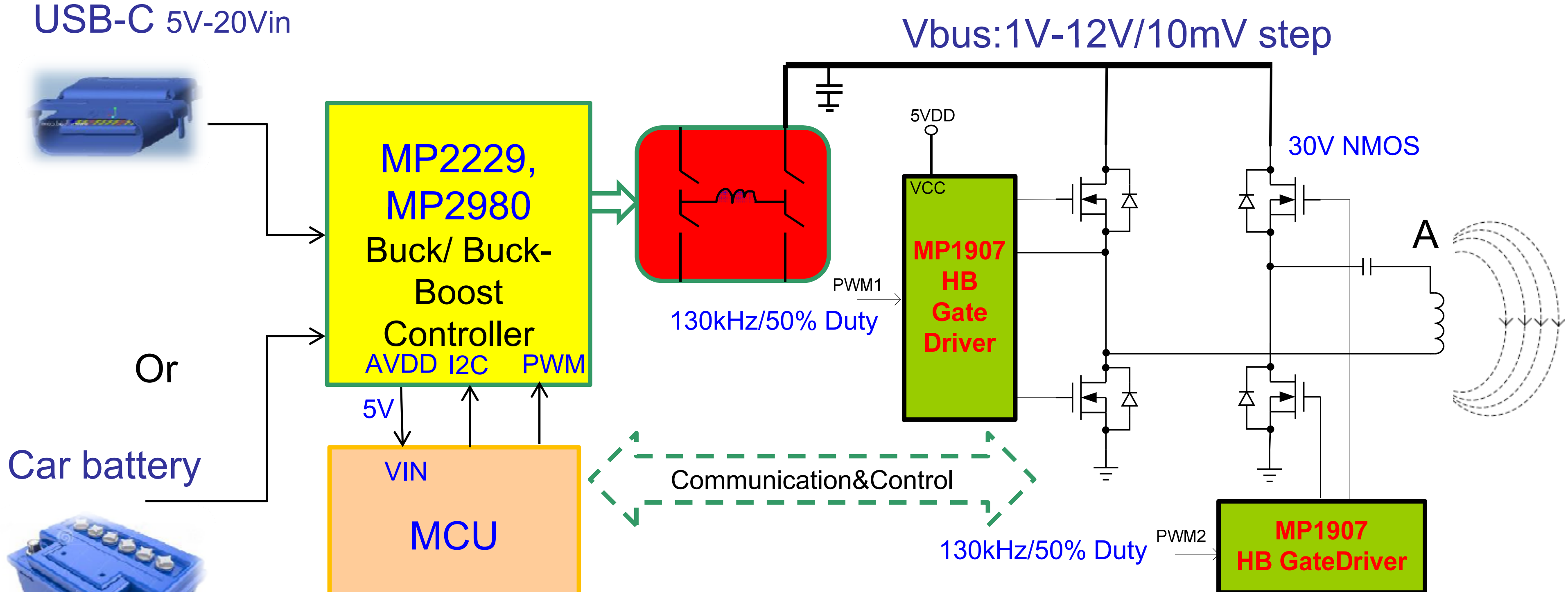
✓Function block: MCU power supply, signal chain and power Inversion.

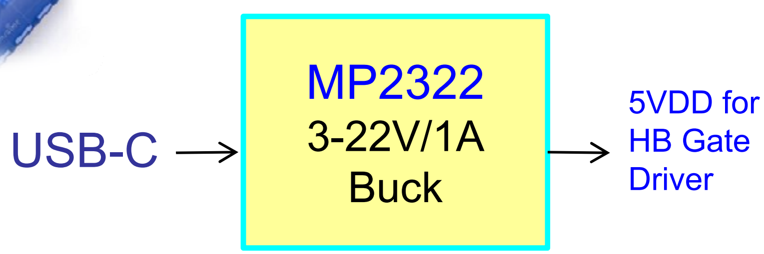
✓Real Design may differ from above, such as Pre-regulator, 5V regulator and High side current sensor is not a must have for some applications

✓Pre-regulator is only needed when input voltage is above 9V, or say12V/15V/19V...(QC/PD/Adaptors) option.

MPS Tx Solution

MP-A5





MP2229	Buck converter to generate 1V-12V adj Vout
MP2980/ MP8859	Buck-Boost w/ I2C to gen. 1V-20V adj Vout
MP2322	22V/1A small Buck to provide Gate Drive Voltage
MP1907	Half-bridge Gate Driver
MP5016H	Input current limit switch

MPS Simple, Easy Solutions

HB Driver&Dr.MOS

MP86901A/B

28V, 20A, Driver-Mos Solution in TQFN Package

Key Features

- Wide Operating Input Range
- 20A Output Current
- Accepts Tri-State PWM Signal
- Built-In Switch for Bootstrap
- Current Sense
- Temperature Sense
- Current-Limit Protection
- Over-Temperature Protection (OTP)
- Fault Reporting: Over-Current and Over-Temperature
- Used for Multi-Phase Operation
- Available in a TQFN-21 (3x4mm) Package

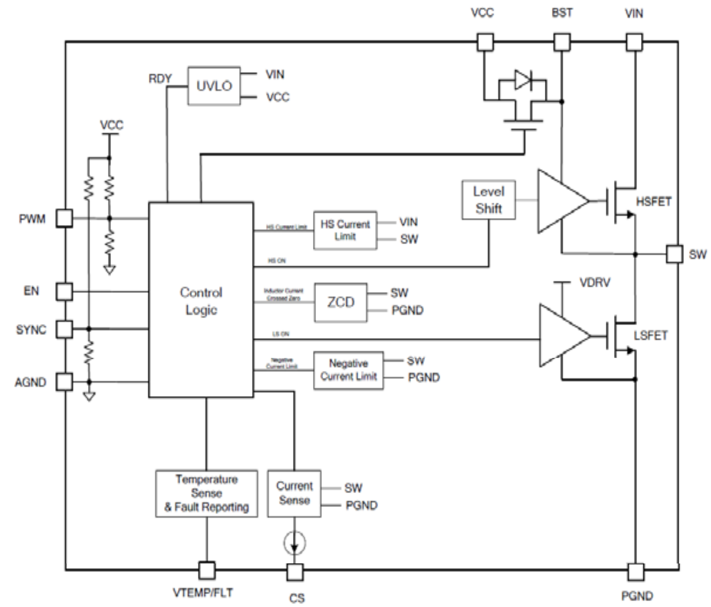


Fig.1 Function Block Diagram

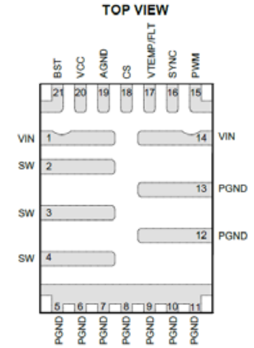


Fig.2 TQFN21(3×4mm)Package

MP1907

100V, 2.5A High frequency Half-bridge Gate Driver

Key Features

- Drives N-channel MOSFET half bridge
- 100V VBST voltage range
- Input signal overlap protection
- On-chip bootstrap diode
- Typical 20ns propagation delay time
- Less than 5ns gate drive mismatch
- Drive 1nF load with 12ns/9ns rise/fall times with 12V VDD
- TTL compatible input
- Less than 150µA quiescent current
- Less than 5µA shutdown current
- UVLO for both high side and low side
- In 3×3mm QFN10 Packages

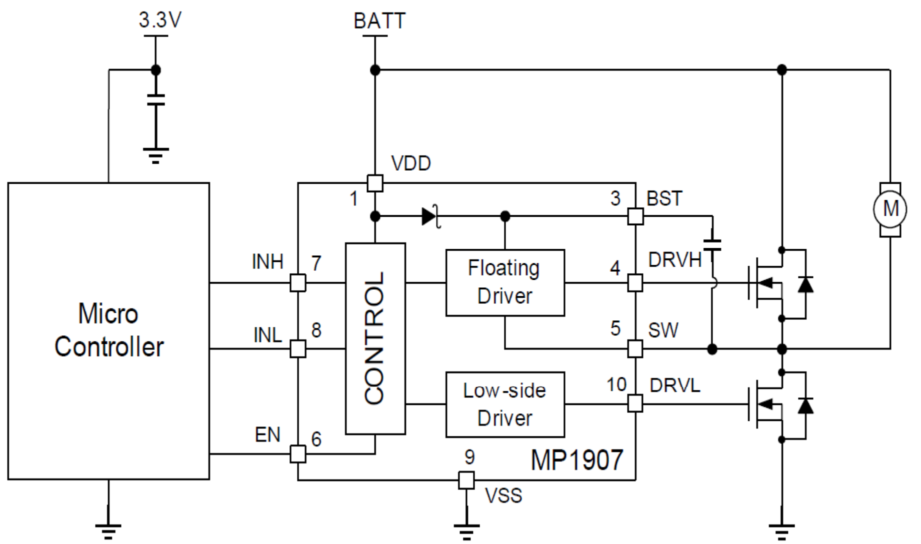


Fig.1 Typical Schematic

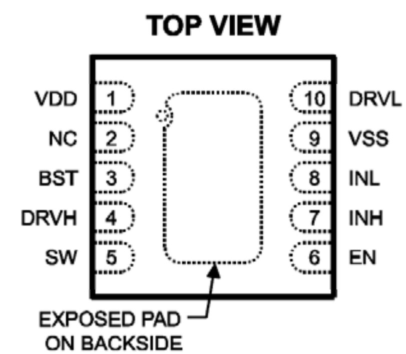


Fig.2 QFN3 ×3mm Package

High Side Current Sensor

MPQ8112
60V, High Side Current Sense Amplifier

Key Features

- Low-Cost, Compact Current-Sense Solution
- 1.8MHz Bandwidth
- 250µA Typical Supply Current
- 2.7V to 60V Operating Supply Voltage
- 0V to 60V Input Common Mode Range
- 3µA Typical Shutdown Current
- 300µV Input Offset Voltage
- High Current Sensing Capability
- Available in SOT563 and 6-Lead TSOT23 Packages

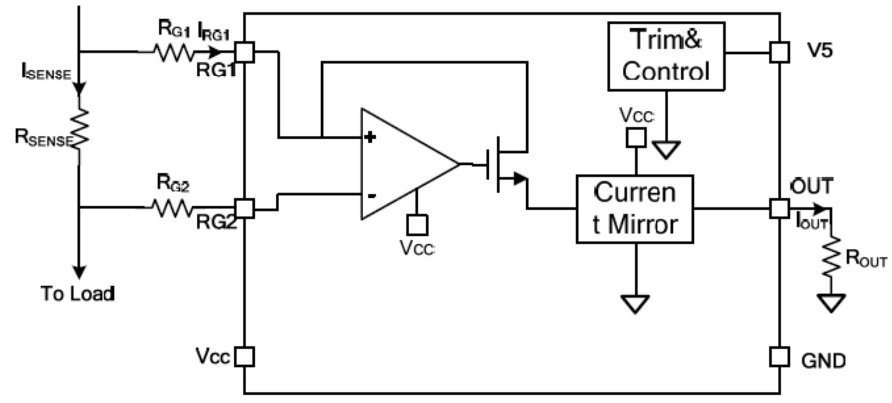


Fig.1 Function Block

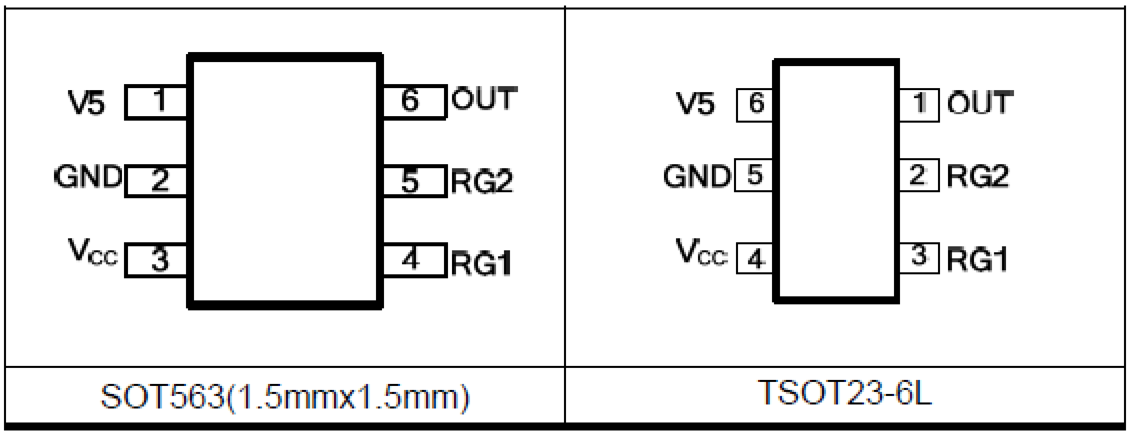


Fig.2 SOT563 and TSOT23-6L Package

Current limit switch

MP5016H

2.7-22V, 0.7-5A, Current limit switch with Over-Voltage Clamp and reverse block

Key Features

- Wide 2.7-22V Operating Input Range
- 26V absolute maximum transient input voltage
- Selectable OVP Threshold
- Fast output OVP response
- Integrated 43mΩ Power MOSFET
- Adjustable Current-Limit or Fixed current limit when Floating ILIMIT
- Reverse block MOSFET driver
- Soft-Start timer programmable through DV/DT and MODE
- Fast response for hard short protection
- Over current protection hiccup protection
- Available in a QFN-10 (1.5x2mm) Package

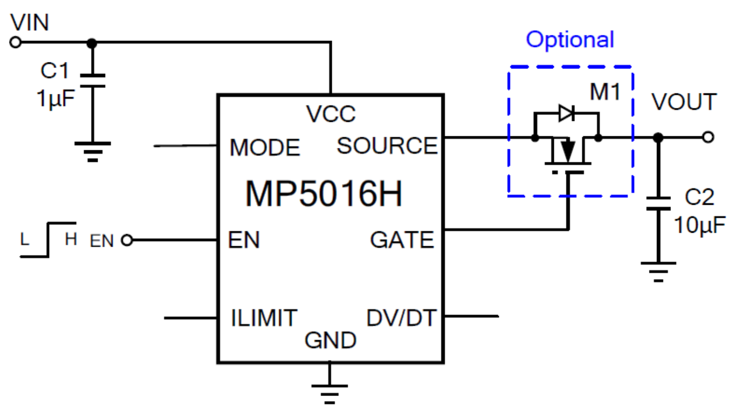


Fig.1 Typical application

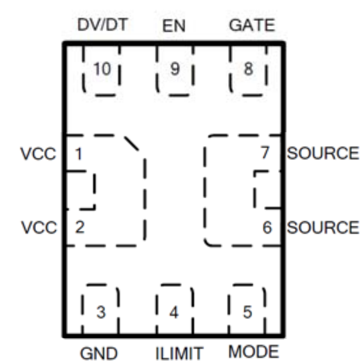
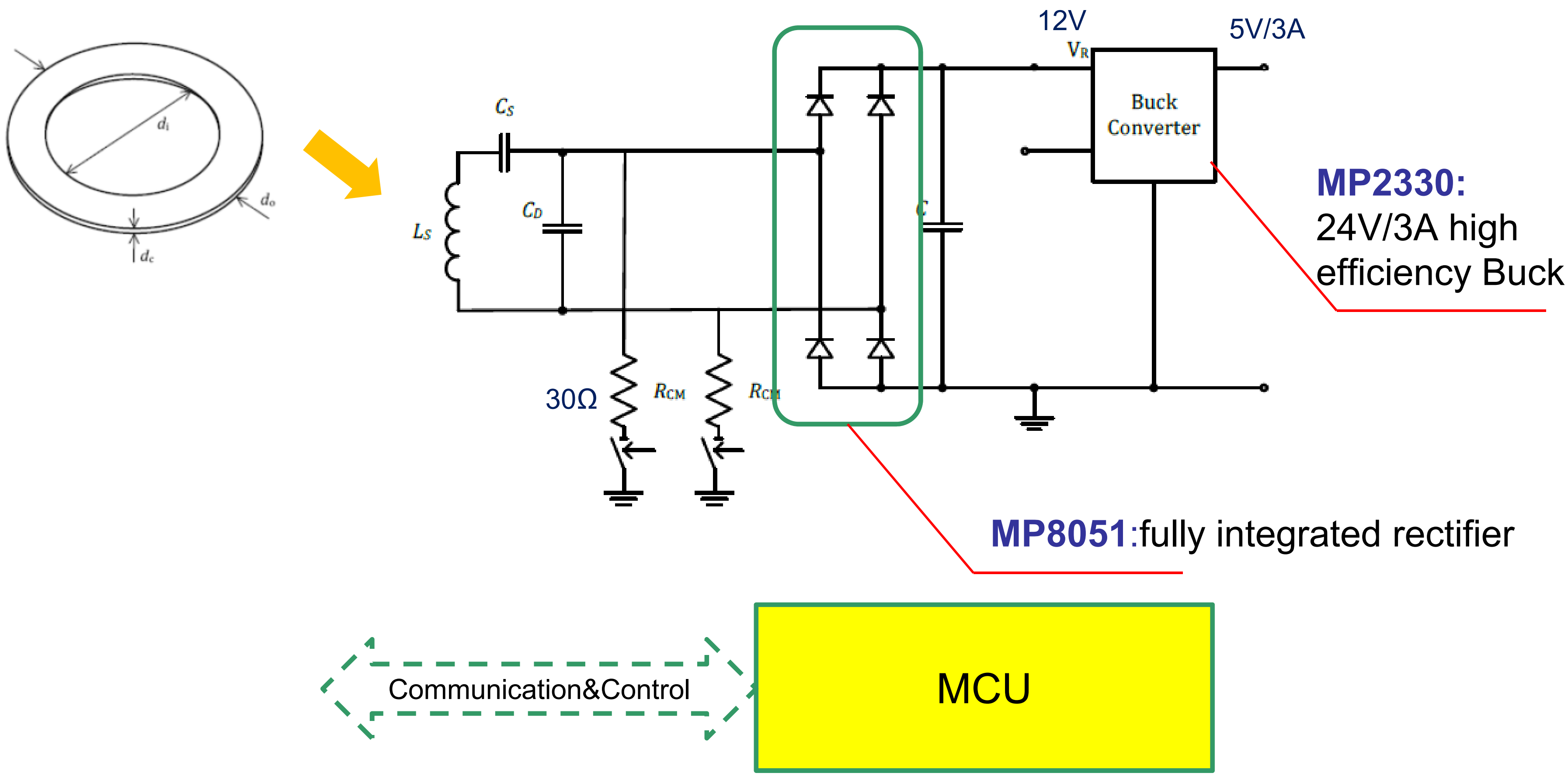


Fig.2 QFN10(1.5×2mm) Package

Power solutions for RX

MPS Rx Side Solution

15W Receiver Example 4:



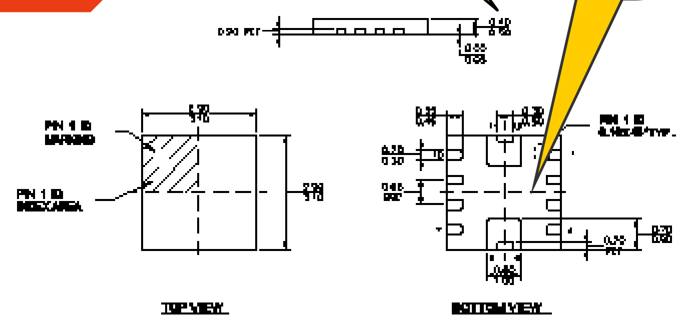
MPS Rx Side Solution – MP8051

MP8051 - Bridge for Wireless Charging Receiver

Space Saving

Smallest Package Height 0.45mm

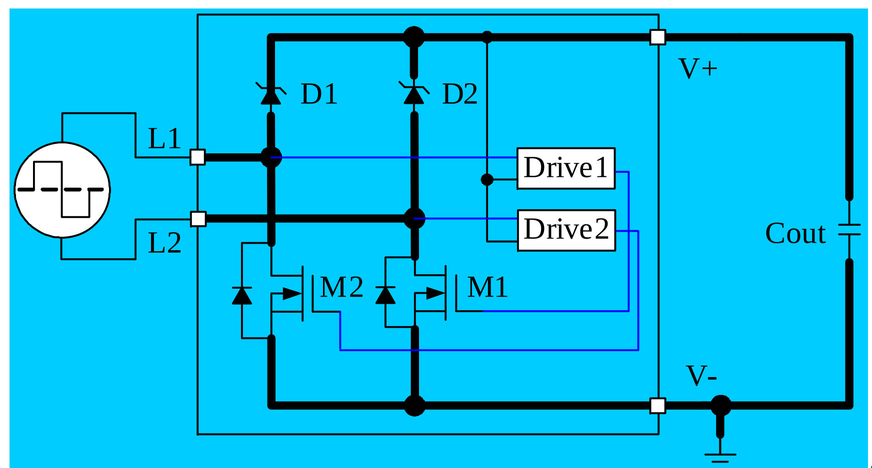
3x3mm TQFN



FEATURES

- Up to 20V input voltage
- 0.4V Forward Voltage Drop
- High Reliability
- Two MOSFETS with 45mΩ Rdson
- TQFN3x3 Package

Simple BOM

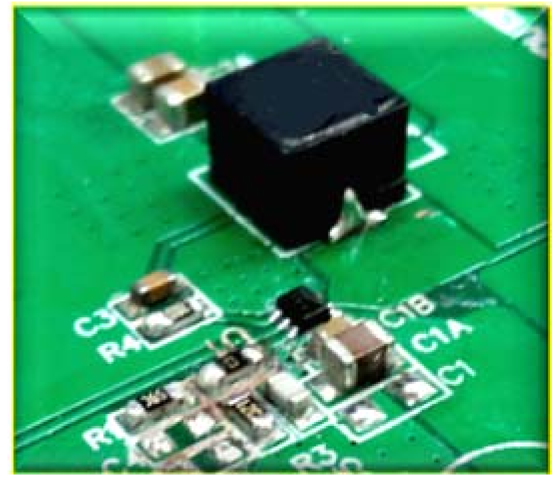


MPS Rx Side Solution – MP2330

MP2330: 24V/3A Sync Buck in SOT583

Space Saving

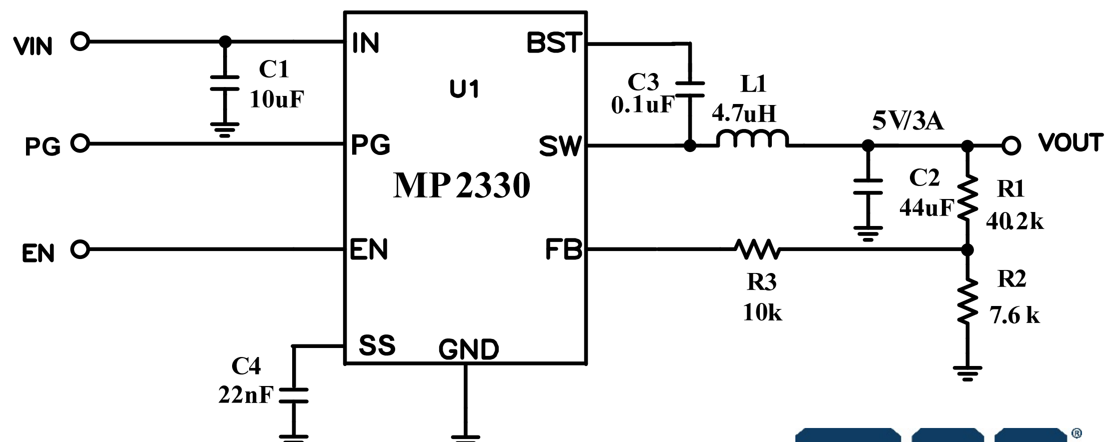
SOT563 1.6mmx1.6mm



FEATURES

- Wide 4.2V-to-24V Operating Input Range
- 70mΩ/40mΩ Low $R_{DS(ON)}$ Internal Power MOSFETs
- COT Control Provide Fast Loop Response
- Low Iq: 200uA
- High-Efficiency up to 95%
- Open Drain PG Indication
- External Soft Start Programmable
- OCP Protection and Hiccup
- Pre-bias Startup
- Thermal Shutdown
- Output Adjustable from 0.8V
- Available in an SOT583 package

Simple BOM



MPS Simple, Easy Solutions

Q&A