Methods for Foreign Object Detection in Inductive Wireless Charging

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Qi Developer Forum
Nov 16, 2017
Agenda

- What’s foreign object detection is all about?
- Major practical FOD methods
- Pros and cons of different FOD methods
- Equating FOD methods
- Summary
What's FOD?

- Googling for ‘FOD’
  - Is it Belgian rock band? – not really
  - The slang expression? – way no
  - Something to do with runway debris -- Not yet

- What FOD means when it comes to wireless power?
  - Foreign Object Detection (FOD) is a safety mechanism which automatically interrupts power delivery if there is interference caused by a foreign object

- What’s foreign object
  - Any object that causes unexpected losses to wireless power transfer
  - Practical examples: coins, paper clips, pharmaceutical wrappers, etc.
First Steps Toward FOD Implementation

- Early in Qi specification development we realized that transmitter electromagnetic field can be coupled into unintended objects with undesired consequences.
- While we never achieving anything close to shown in these pictures, the concerns were high.
- Small metal objects like coins, paper clips, pieces of foils and pharmaceutical wrappers when placed between the transmitter and the mobile device can heat up to over 100°C in a matter of seconds.
- This can be enough to permanently mar the mobile device surface or inflict first degree skin burn.
- WPC initiated Foreign Object Detection task force in 2010 and made this safety feature a mandatory in 2011.
Major Practical FOD Methods

Q-factor Method: Before Power Transfer
Loss Balance Method: During Power Transfer
FOD Methods: Q-factor Measurement Before Power Transfer

- Small signal field is established from TX coil to measure Q-factor
- Q-factor is measured either
  - in time domain as a decay rate of TX coil self-resonance
  - or in frequency domain as a ratio of the peak frequency to the system bandwidth
- Measured value can be used as criterion to enable charging, or compared to some reference value later communicated from RX to TX
- The last method is more flexible and allows for better interoperability
**Q-Factor FOD Flow**

**Development Phase**

**TX** Implement Q-factor measurement mechanism

**RX** Measure with LCR meter Q-factor value of your RX device & program it into RX FW

**Operation Phase**

**Step 1** Measure Q-factor & Store its value for negotiation state

**Step 2** Start power contract negotiation & receive RX reference Q-factor value

**Step 3** Compare measured and RX reference Q-factor values & make decision on enabling power transfer
FOD Methods: Loss Balance During Power Transfer Stage

- All losses are accounted for on transmitting and receiving sides
- Received Power is communicated to TX side and balanced with Transmitted Power
- The remaining difference is attributed to FO Losses and is compared with the set threshold
- Qi standard mandates interrupting wireless power transfer if FO dissipation exceeds limits
  - BPP $P_{FO} > 350mW$
  - EPP $P_{FO} > 750mW$
The EPP profile may include receiving from RX loss calibrating coefficients for more precise FOD threshold.
Calibrating FOD

- Successful loss balance FOD implementation requires individual calibration of most contributing components like TX coil and power amplifier.
- Loss balance method can reliably intercept FO dissipating $\sim 300\text{mW}^+$.
## Losses Detected by FOD Methods

### FOD Before Power Transfer

- **RX Side**
  - Rx Shield Magnetizing Losses
  - Eddie Current Losses in Friendly Metals – mainly the battery and mobile device frame

- **TX Side**
  - Conductive Losses in Tx Coil & FETs
  - TX Shield Magnetizing Losses

### FOD During Power Transfer

- **RX Side**
  - Conductive Losses in Rx Coil and Rectifiers
  - Rx Shield Magnetizing Losses
  - Energy consumed by control circuits
  - Eddie Current Losses in Friendly Metals – mainly the battery and mobile device frame

- **TX Side**
  - Conductive Losses in Tx Coil & FETs
  - TX Shield Magnetizing Losses

- **FOD before power transfer deals with potential quality of WPTS**
- **FOD during power transfer deals with effectiveness of WP transfer**
Equating FOD Methods

Applying common approach
Equating FOD Methods

- Q-factor is a unitless measure of potential power loss in the mobile device body during power transfer
- Q-factor is unitless measure of how much Apparent Power exceeds the Real Power in the AC system
- Q-factor is inverse value of the power factor -- $\cos \phi$ (Cos Phi)
- Power dissipated in FO can be a measure of equating FOD requirements for different methods

For every WPTS it is possible to predict maximum FM and FO dissipation based on system power and measured Q-factor

\[
\cos \phi = \frac{P}{S} = \frac{I^2 R}{I^2 + \omega L} = \frac{R}{\omega L};
\]
\[
Q = \frac{\omega L}{R} = \frac{1}{\cos \phi};
\]
\[
P_{FO} = \frac{S_{IN}}{Q_{FO}}; \quad Q_{FO} = \frac{S_{IN}}{P_{FO}};
\]
Three power systems compared:
- BPP $P_o=5$ W
- EPP $P_o=15$ W
- MP $P_o=60$ W

The same Q-factor value is associated with different power loss in BP, EPP and MP system.
For example, $Q=20$ equals to
- BP $=0.35$ W
- EPP $=1.10$ W
- MP $=4.50$ W

Current Qi spec requires FO loss during power transfer for BPP system to be less than $P_{FO} < 0.35$ W.
For EPP system -- $P_{FO} < 0.75$ W. This translates into a requirement for $Q>30$

- The higher the system rated power the higher should be the minimum allowed mobile device Q-factor
- The higher is rated power the lower efficiency drops for the same Q value
Pros & Cons of FOD Methods

FOD Before Power Transfer

**PROS:**
- No energy is put into FO on detection stage
- Higher precision and better resolution
- Resolution is independent from power level
- Measured Q-factor values can be correlated to LCR meter
- FO detection is very quick — hundreds of microseconds

**CONS:**
- One time action at the very beginning of WPT
- Doesn’t protect from tampering during power transfer
- Resolution degrades in small Q-factors (high content of Friendly Metals)

FOD During Power Transfer

**PROS:**
- Always on-guard when TX is energized
- Tampering during power transfer is easily intercepted
- Less susceptible to Friendly Metals
- Works well in low and highly resonant systems

**CONS:**
- Steady power transfer should be established for some time for the method to work
- Can false trigger in load transients
- Some energy is put into FO raising it temperature
- As transmitted power increases the method precision and resolution are challenged

- Both methods have important pros & cons
- Use of both methods in WPT system gives the best result and user experience
Foreign object heat up is very undesirable in the eye of mobile device manufacturers

Qi standard demands interrupting wireless power transfer when losses in foreign object exceed certain amount

There are several methods to detect foreign objects
  • Before power transfer
  • During power transfer

Combination of foreign object detection methods provides the best protection

Be aware of gimmicks and fake products on the market. Use only Qi certified solutions
Closing Remark:
Choose Most Advanced FOD Implementations for your Qi Products

PICK UP FOD
Foreign Object Detection

MAKE A DIFFERENCE

DESIGN PROPER FOD
into your Wireless Power Transfer System with RichTek Transmitter and Receiver Chips

RT3181, RT165x