Methods for Foreign Object Detection in Inductive Wireless Charging

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Qi Developer Forum
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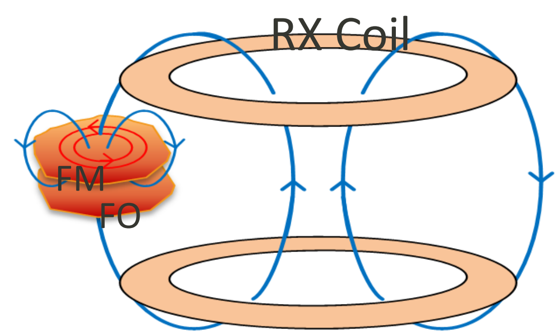
Agenda

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

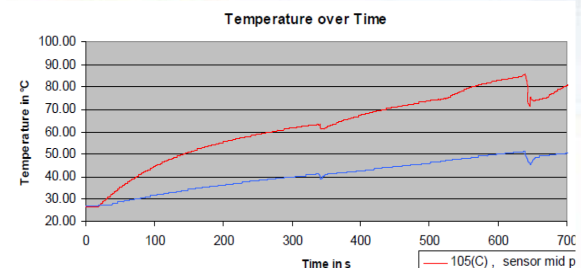
What's FOD?

- 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.*

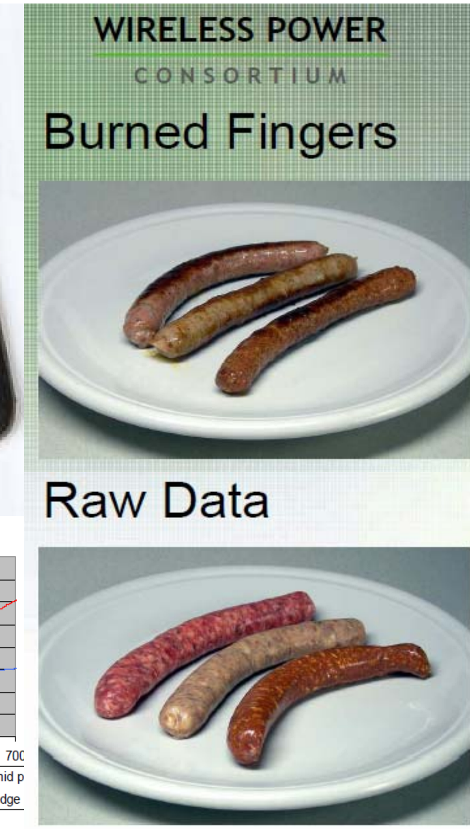


First Steps Toward FOD Implementation

- 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



Case 2 with FM



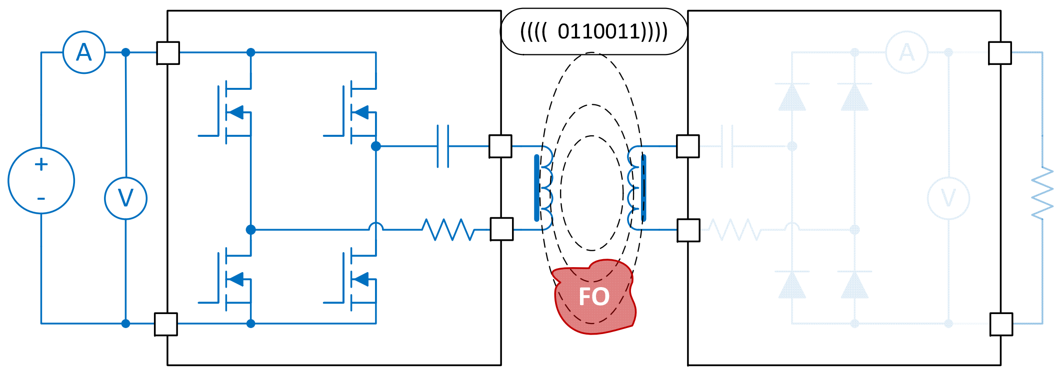
Circa 2010

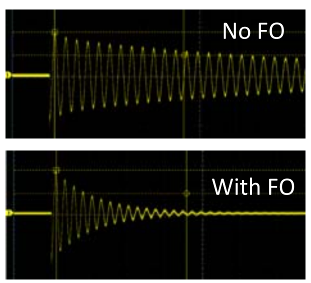
Major Practical FOD Methods

Q-factor Method: Before Power Transfer

Loss Balance Method: During Power Transfer

FOD Methods: Q-factor Measurement Before Power Transfer





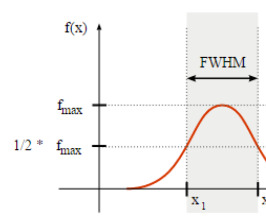
Time domain

$$V(t) = V(0) \cdot \exp[\frac{-\omega \cdot t}{2 \cdot Q}]$$

$$\omega = \frac{2\pi}{T}$$

$$Q = \frac{\pi \cdot (t_2 - t_1)}{T \cdot \ln[\frac{V(t_2)}{V(t_1)}]}$$

Frequency domain



$$Q = \frac{f_O}{\Delta f}$$

- 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

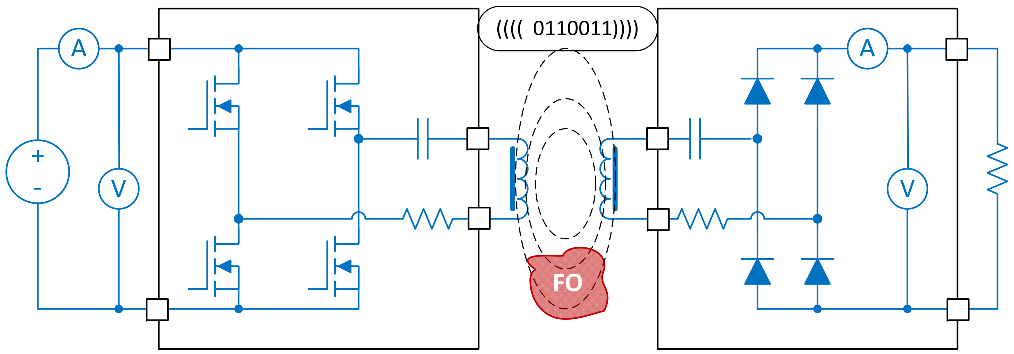
Operation Phase

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



$$P_{FOD} = (P_{IN} - P_{TX\_LOSS}) - (P_{OUT} + P_{RX\_LOSS})$$

Transmitted Power

Received Power

- 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

Loss Balance FOD Flow

Step 1 RX approximates Received Power Value & sends it to TX

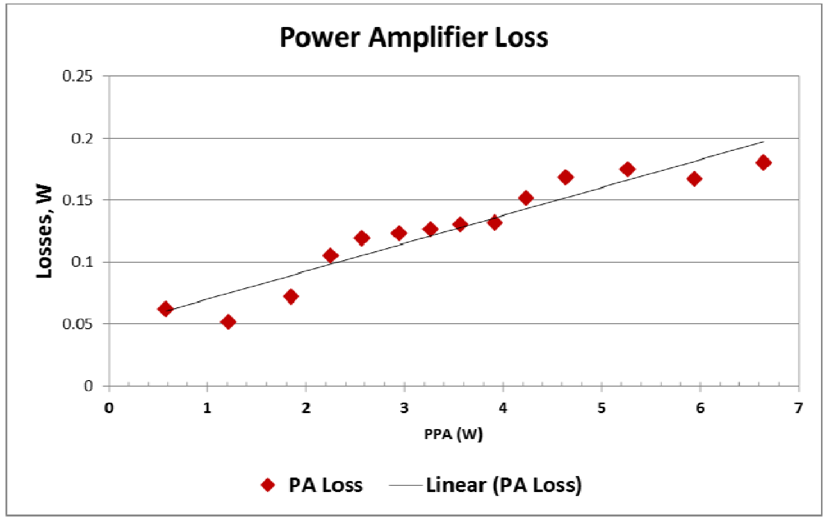
Step 2 TX calculates its losses and approximates Transmitted Power

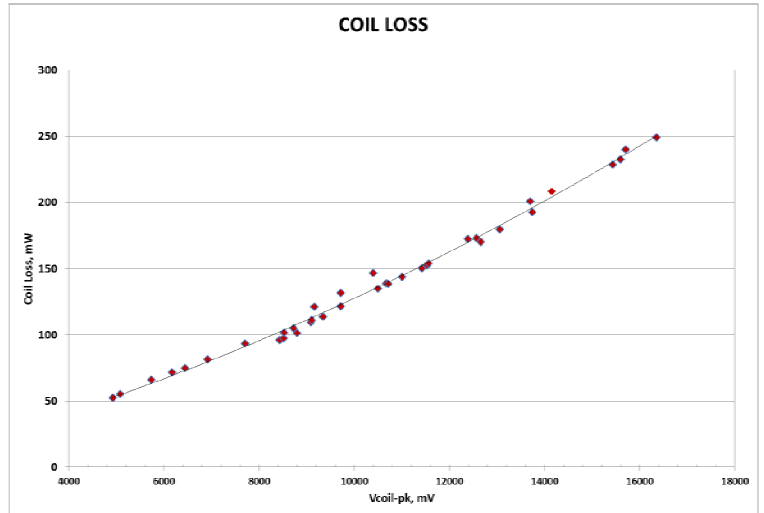
Step 3 TX receives Received Power Value from RX

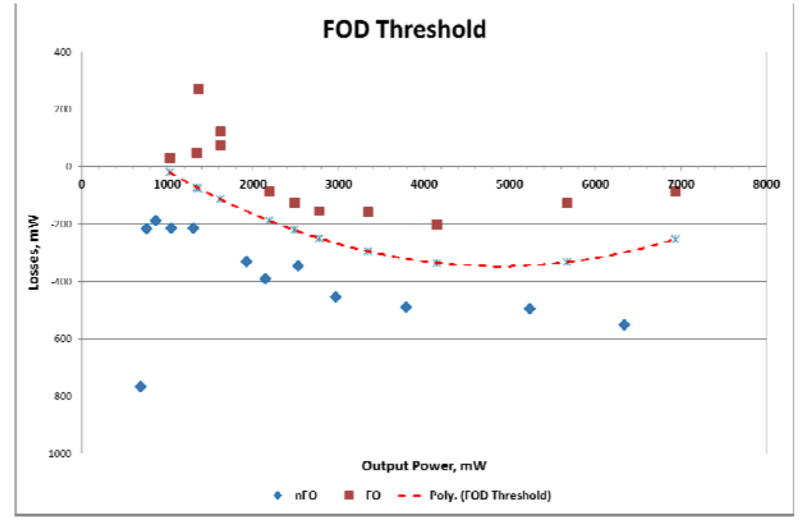
Step 4 TX calculates difference between Transmitted and Received Power & makes decision on terminating power transfer

- 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 ~300mW^{+}

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

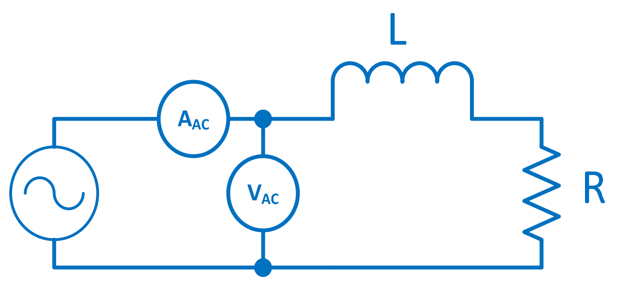
- **RX Side**
  - Conductive Losses in Rx Coil and Rectifiers
  - Rx Shield Magnetizing Losses
  - Energy consumed by control circuits
  - Eddie Current Losses in Friendly Metals – mainly the battery and mobile device frame
- **TX Side**
  - Conductive Losses in Tx Coil & FETs
  - TX Shield Magnetizing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

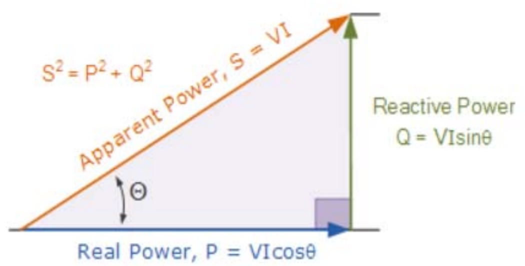
- **FOD before power transfer deals with potential quality of WPTS**
- **FOD during power transfer deals with effectiveness of WP transfer**

Equating FOD Methods

Applying common approach

Equating FOD Methods





Power Triangle

$$\cos\varphi = \frac{P}{S} = \frac{I^2 R}{I^2 \varpi L} = \frac{R}{\varpi L};$$

$$Q = \frac{\varpi L}{R} = \frac{1}{\cos\varphi};$$

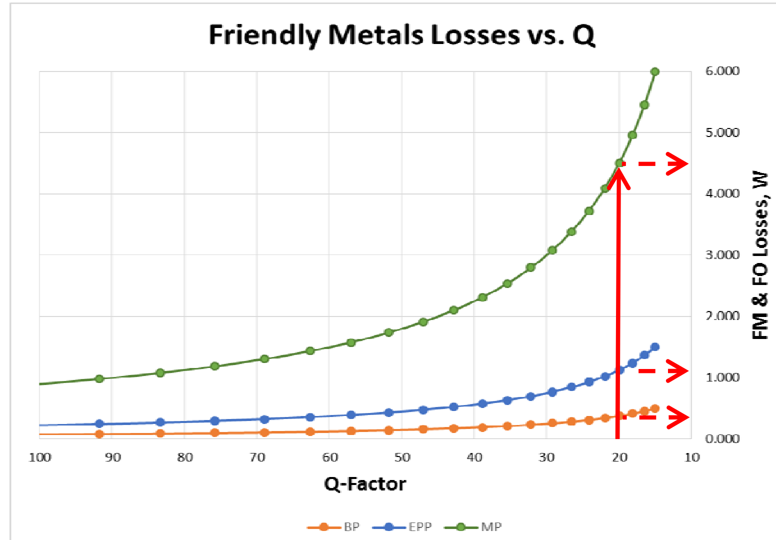
$$\boxed{P_{FO} = \frac{S_{IN}}{Q_{FO}}; \quad Q_{FO} = \frac{S_{IN}}{P_{FO}};}$$

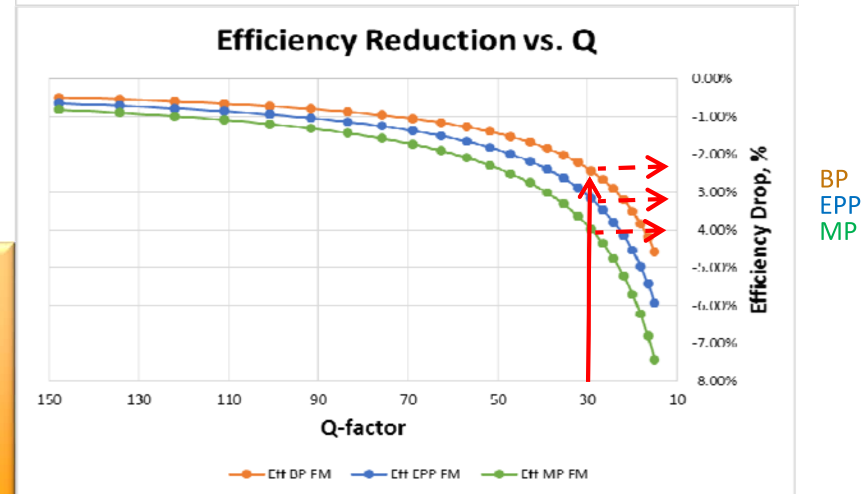
- Q-factor is a unitless measure of potential power loss in the mobile device body during power transfer
- Q- factor is unitless measure of how much Apparent Power exceeds the Real Power in the AC system
- Q-factor is inverse value of the power factor -- cosφ (Cos Phi)
- Power dissipated in FO can be 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

Losses In Foreign Objects vs. Q-factor for Systems with Different Rated Power

- Three power systems compared:
  - BPP Po=5 W
  - EPP Po=15 W
  - MP Po=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 micro seconds
- 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**

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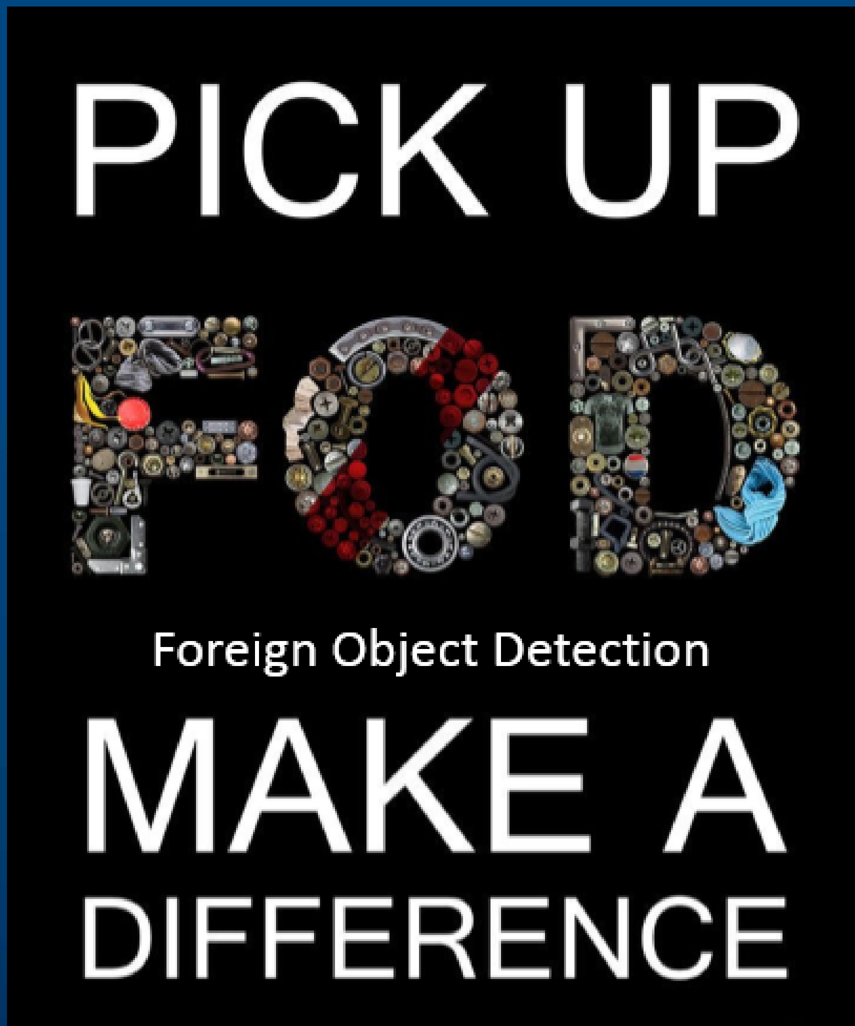
Summary

- 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



DESIGN PROPER FOD

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into your Wireless Power Transfer System with

RichTek

Transmitter and Receiver Chips

RT3181, RT165x

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