Path to First Try Success Making Qi Compliant PTx and PRx

Making things go right for a change

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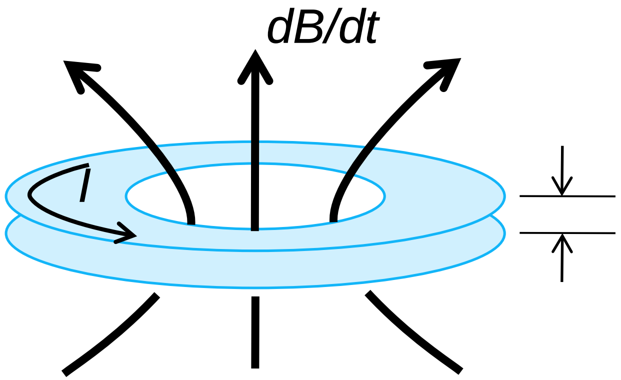
Overview

- Introduction
- Implementation Flow
- Practical Design Tips and Tricks
- Important Testing to Do

Question: Why Is Wireless Power So Hard???

Straightforward

Rocket Science



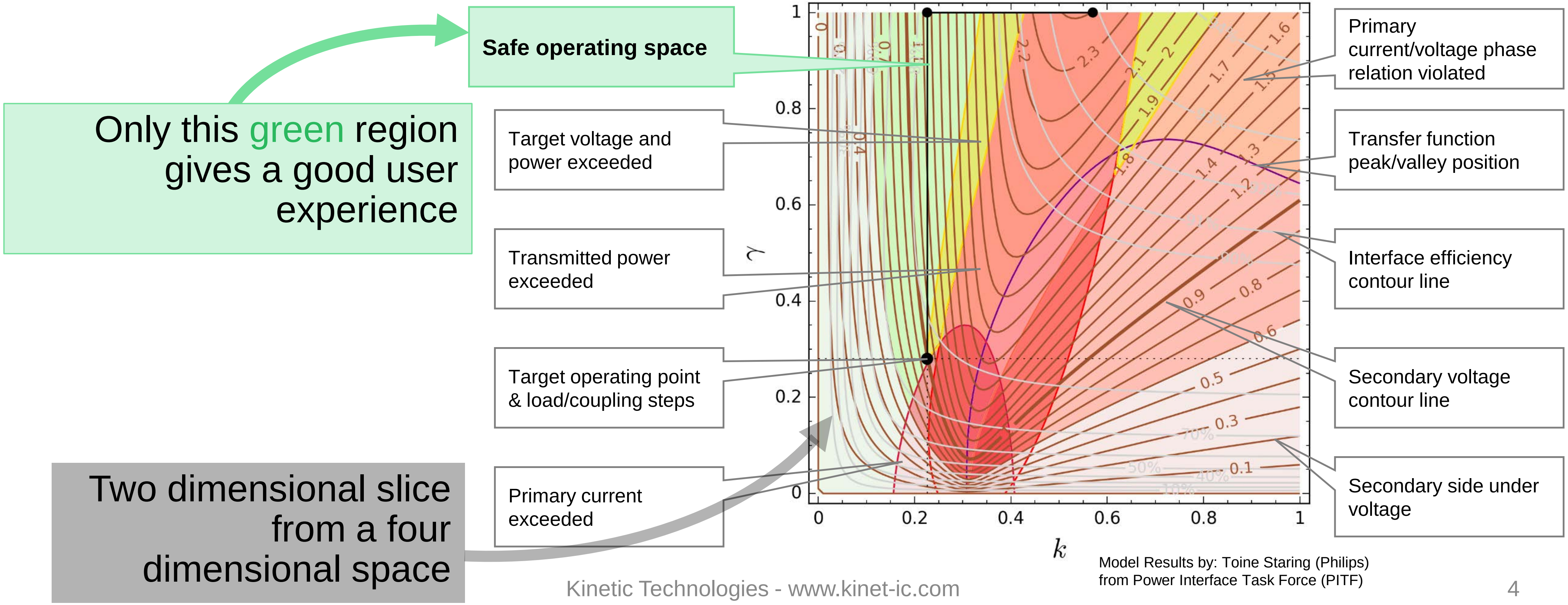
Wireless Power

Increasing Difficulty

Answer: It Is Actually a Little Bit Difficult !

- Humans have a poor intuitive understanding of magnetics.
- Loosely coupled electromagnetic systems are complicated.

WIRELESS POWER OPERATING SPACE MAP



Model Results by: Toine Staring (Philips) from Power Interface Task Force (PITF)

To Navigate This Path

- **If you are not a very experienced wireless power expert:**
  - It is important to work with an experienced guide who can help you on your journey.
  - If you do not require a proprietary solution, choose a standards based solution such as Qi.

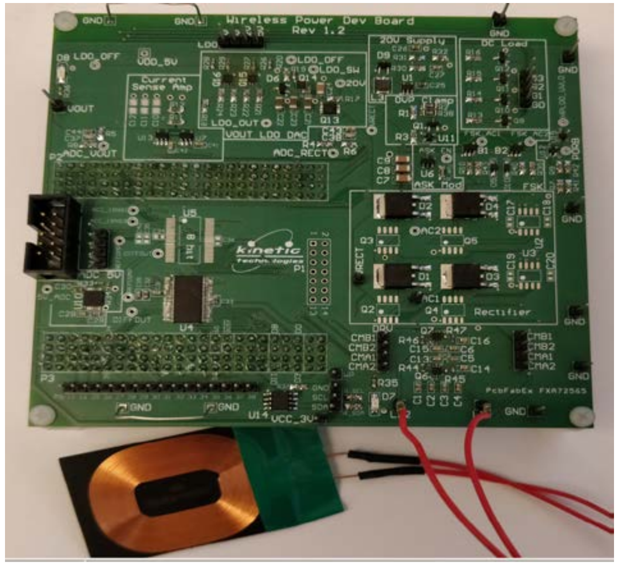
- Standards specifications such as Qi provide reliable map and combined with expert help, these are important to keep PRx and PTx working together in the **GREEN** region:
  - Qi Specifications
  - Standards based test procedures and specialized tools
  - WPC developer resources

- Use this presentation as a road map to read later ! Do not worry if we skip quickly through many of the key points.

Role of IC Company as Systems Integrator

- The IC maker is a key driver of commercialization and commoditization by making complex technology easy to use.
  - … when the cost and business opportunity make sense !

Many Experts
$$$$$$$$
Months or Years



1 Engineer
< US$1.00
Hours or Days

Design Implementation Flow (Qi oriented)

1. Find an experienced partner strong in wireless power PRx/PTx design and share information frequently with this partner
2. Do the industrial and mechanical design first (instead of last)
   a) Very important for temperature and cooling management
   b) Also has a big effect on easy/hard adjustment of FOD (Foreign Object Detection)
3. In addition to doing all the normal good engineering processes, also do the special WPC engineering such as we talk about here.
4. In addition to doing all the normal good testing processes, also do the special WPC related testing such as we talk about here.
5. Finally, do as much “end user” and pre-compliance testing as possible.
   a) Test a variety of PRx/PTx combinations and check for always good end-user experiences
   b) If possible, test with WPC type test tools to verify that all compliance tests can pass.
6. Prepare completely the WPC Self-Declaration forms and five test units that are required for formal compliance testing.

PTx Industrial and Mechanical Design

- Biggest decision = choose best transmitter type for the application
  - Many electromechanical details of transmitter are completely defined by WPC
  - Important to follow min-max PTx spacer distances written in the specifications to stay in green zone
  - Keep “friendly metals” away from PTx coil area – preferably 8mm or farther from coil. Metallic paints or EMI shielding can also cause problems similar to actual metals!
  - There are coil vendor tradeoffs of quality, cost, etc. even for the exact same PTx type coil.
    a. Ferrite can have non-linear loss with increased flux – difficult for FOD tuning and/or fail Guaranteed Power
    b. Ferrite may not fully shield metal behind coil – difficult for FOD tuning, and/or fail Guaranteed Power
    c. Ferrite may become saturated at higher flux – very difficult for FOD tuning Saturation causes flux to pass through ferrite into metals behind coil. Can also result in failing Guaranteed Power compliance tests
- Thermal design is very important – have a plan to keep PTx heat away from PRx
  - How does heat move away from the wireless power chip, coil, etc. into the environment?
  - Important to keep PTx heat away from PRx (such as phones)
Phone charging will <u>slow down</u> if the phone gets hot !
  - The main PTx coil itself does not make much heat.
- Other issues to study carefully early:
  - EMI design
  - Acoustic design – capacitors and coils can make noise, and mechanical design can make this louder
  - Usability – will PRx be easy to position and stay placed. Vibrations from charging can move PRx!

PRx Industrial and Mechanical Design

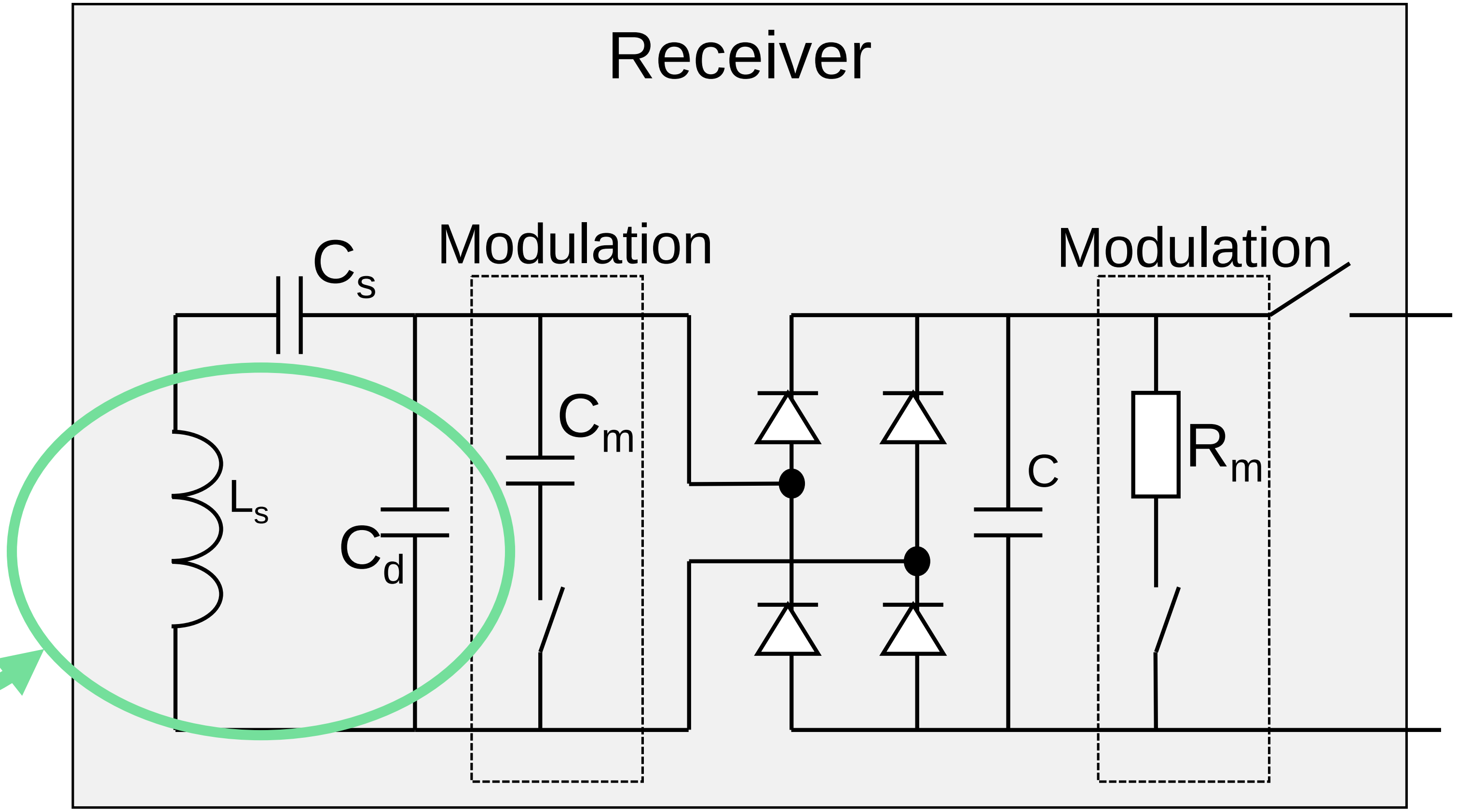
- Biggest decision = choose a “good” coil design for the application
  - Number of coil turns and coil physical dimensions: Typically 11-15 turns depending on application
    More turns makes it easier to make required PRx voltages, but make larger coil with more losses/cost
  - Square area: Generally the biggest square area to collect magnetic flux from PTx is good
  - Inductance: Generally, the inductance is an indirect result of size, turns, ferrite choices
    Affects mainly the choice of series-resonant capacitors to achieve the required 100kHz resonace
  - Keep “friendly metals” away from PRx coil area – preferably 8mm or farther from coil
    Metallic paints or EMI shielding can also cause problems similar to actual metals!
  - Choose reasonable AC-coil resistance (typically: 100 – 500mΩ (cost, quality, thickness tradeoff !)
    PRx coil current can be larger than DC current. Coil resistance is often #1 factor in PRx efficiency !!
  - Ferrite shielding material quality = #1 cause of surprise problems
    a. Ferrite can have non-linear loss with increased flux – difficult for FOD tuning
    b. Ferrite may not fully shield metal behind coil – difficult for FOD tuning
    c. Ferrite may become saturated at higher flux – very difficult for FOD tuning
- Thermal design is very important – have a plan to move heat away from wireless power area
- Other issues to study very carefully early:
  - EMI design
  - WPC recommended coil spacer is approximately 1.0-1.5mm. Too small <<1mm can cause problems.
  - Acoustic design – capacitors and coils can make noise, and mechanical design can make this louder

Basic PRx WPC Requirements

1. After choosing PRx, coil adjust Cd for 1,000kHz resonant frequency.

This is to meet WPC requirement for PTx with moving coils that need to locate the PRx coil.

Important to do this adjustment in final product, but without any PTx coil present. The reason not to have PTx coil is because on the real PTx that has a moving coil, the PTx coil is far away when the PTx is trying to locate the PRx coil.

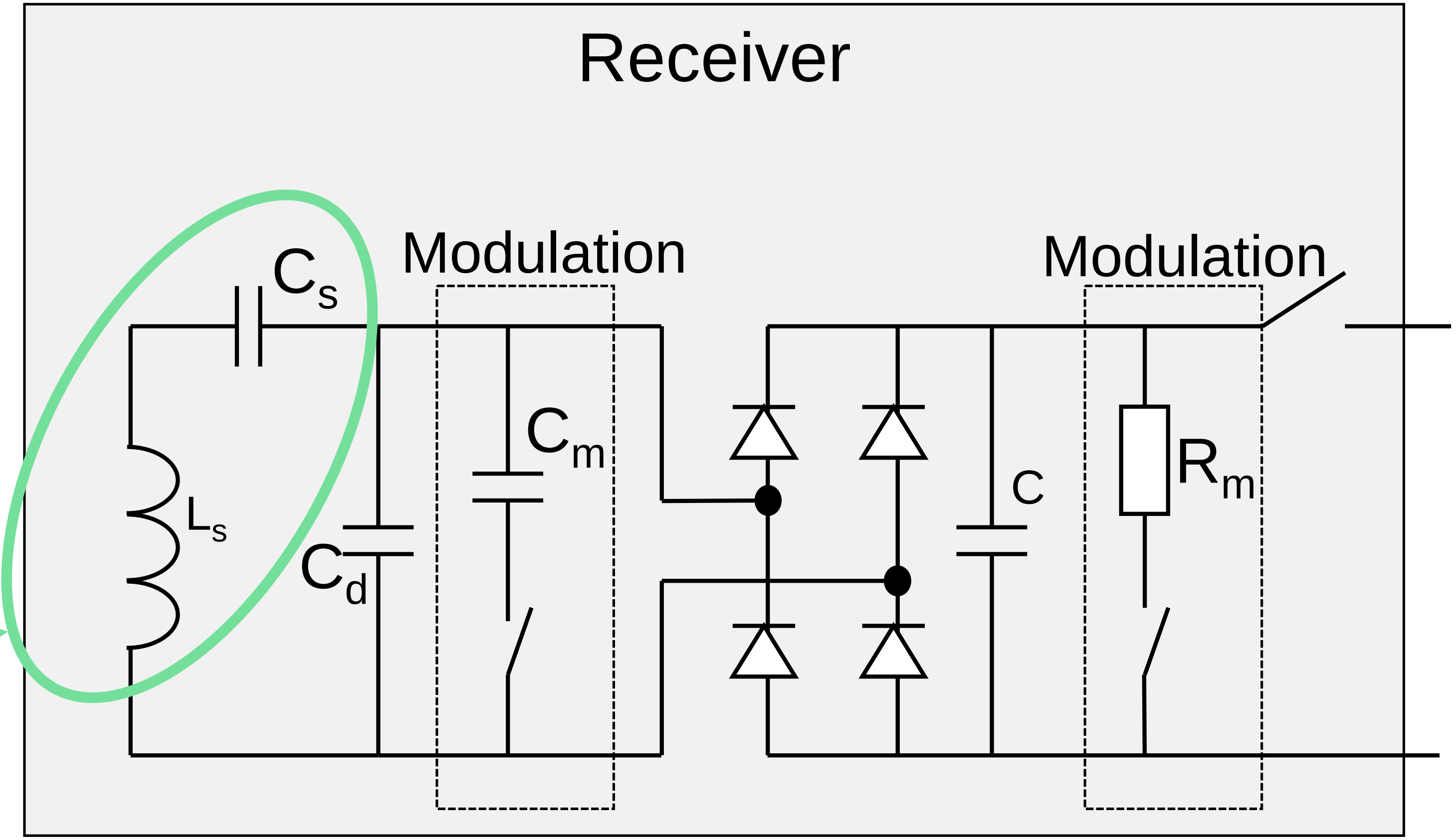


Basic PRx WPC Requirements

2. Adjust Cs capacitor for 100khz resonant frequency which is normally best when set as required by WPC specifications with PTx shield nearby.

Important to do this adjustment in final product, and with a PTx coil present with the typical 2mm PTx spacer material on top of the PTx coil.

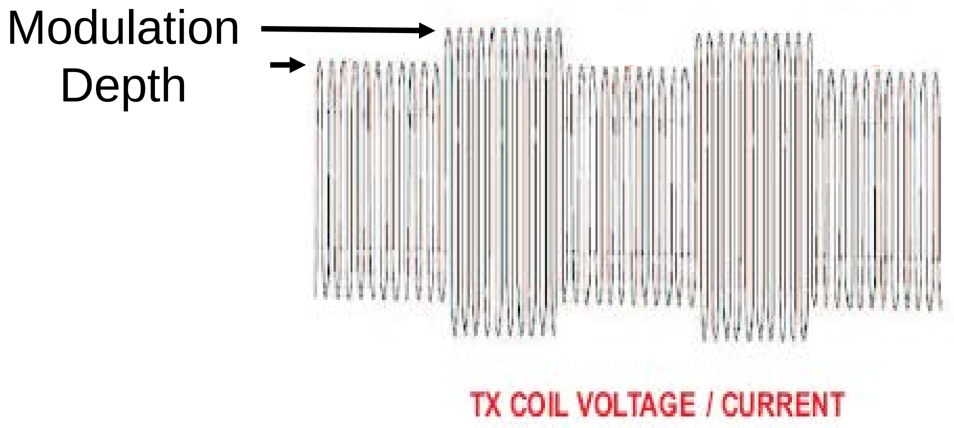
Note: Follow Receiver partner recommendations for Cs ESR specifications and voltage rating.

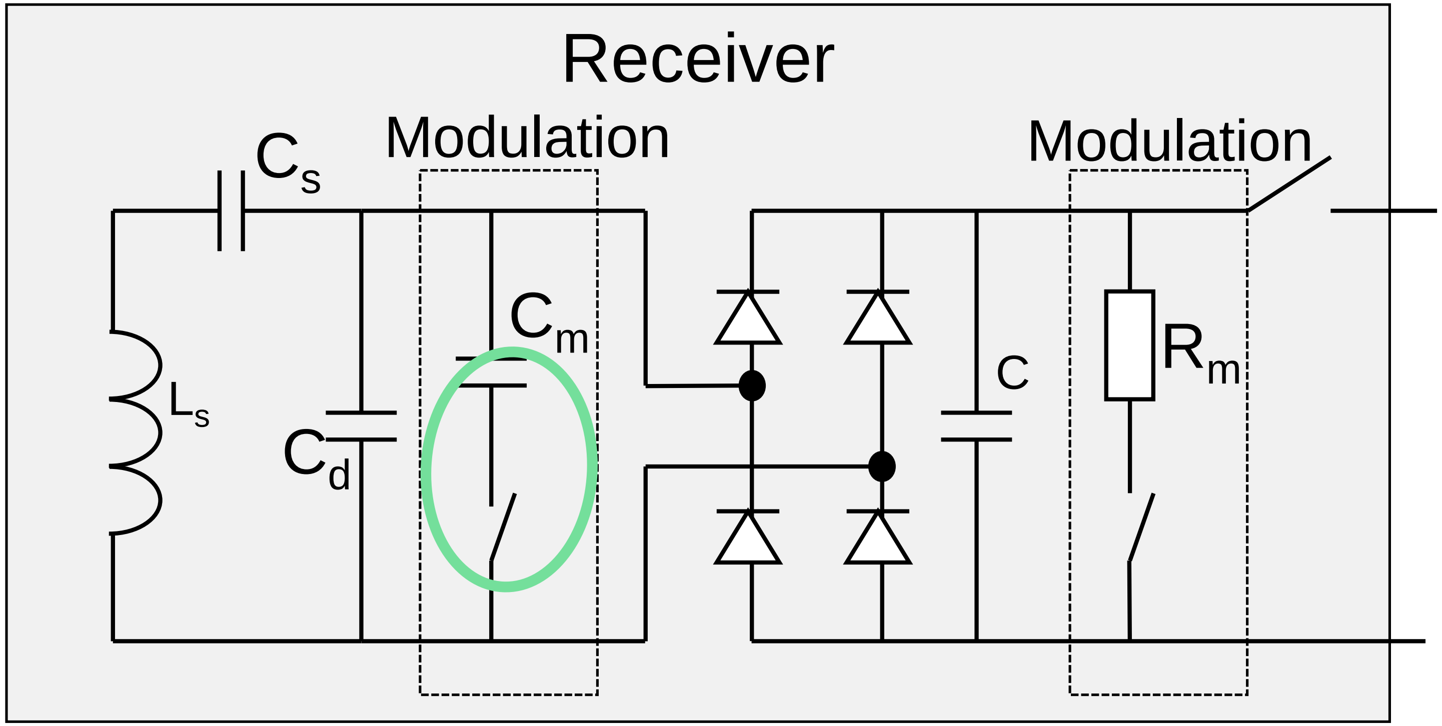


Basic PRx WPC Requirements

3. Follow Receiver partner recommendations for Cm (which sets the modulation depth) and other component values to complete the system. (Normally Rm is inside a receiver chip if it is used.)

VERY IMPORTANT: Discuss with your Receiver partner the design and be sure to share the mechanical / PCB layout, schematic, and BOM parts list for review before sending out for fabrication!





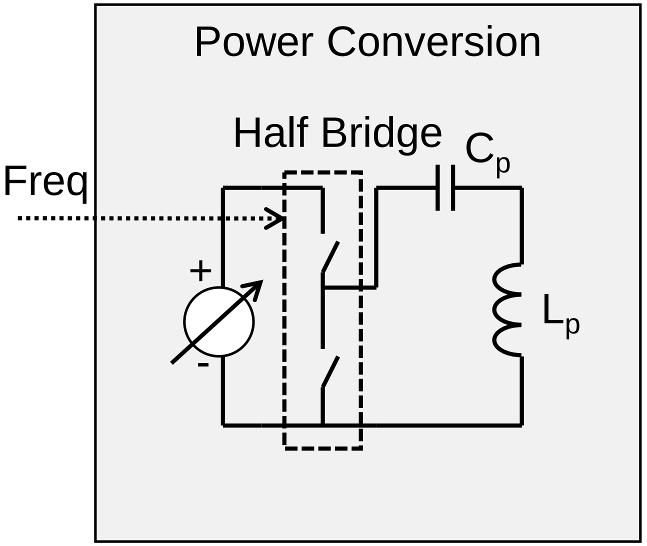
Basic PRx WPC Requirements

4. Work with Receiver partner to adjust all of these things when the system is working in its final form:

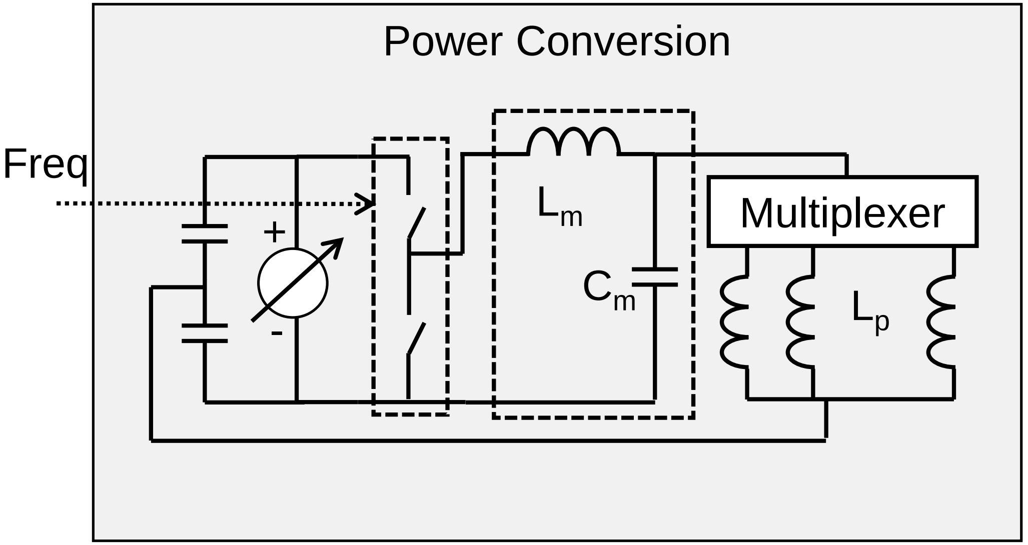
   - Modulation Depth
     - Follow the WPC test procedure to measure modulation depth. This is the strength of the ASK (Amplitude Shift Keying) signal that PRx uses to communicate with PTx. If necessary, work with Receiver partner to adjust modulation depth. It is normally best to adjust this close to the maximum allowed so that communication with PTx is strong under all conditions.
       Note: It is a must to do all of the WPC modulation depth measurements which are required to be submitted as part of the PRx Self Declaration form when PRx is ready for official compliance testing.
   - FOD Adjustment
     - Adjust the FOD for good pass/fail margin. For compliance testing, it is usually best to set the "over reporting" allowance close to the maximum limit. This could risk a 'fail' in official compliance testing, but makes the system less likely to fail Interoperability Testing (IOP) or causing false FOD for end users.
   - Q-factor Value (required for EPP <Extended Power Profile> Receivers)
     - Follow WPC test procedure to determine Q-factor value PRx should report to PTx. As with FOD, it is normally best to choose a value that has some risk of compliance test failure and low risk of IOP failure.

WPC Basic Transmitter Topology

- Primary coil (L_p) + serial resonance capacitor (C_p)
- DC-to-AC Inverter: e.g. half bridge (shown below) or full-bridge
- Power level is controlled by changing transmitter operating frequency, operating duty cycle, and/or bridge supply voltage.
- Power is controlled by the Receiver which is the master of the transmitter
- Multiple coil solutions function the same as single-coil with the “best” coil selected by the transmitter before beginning interoperation with the Receiver



Single Coil



Multiple Coils

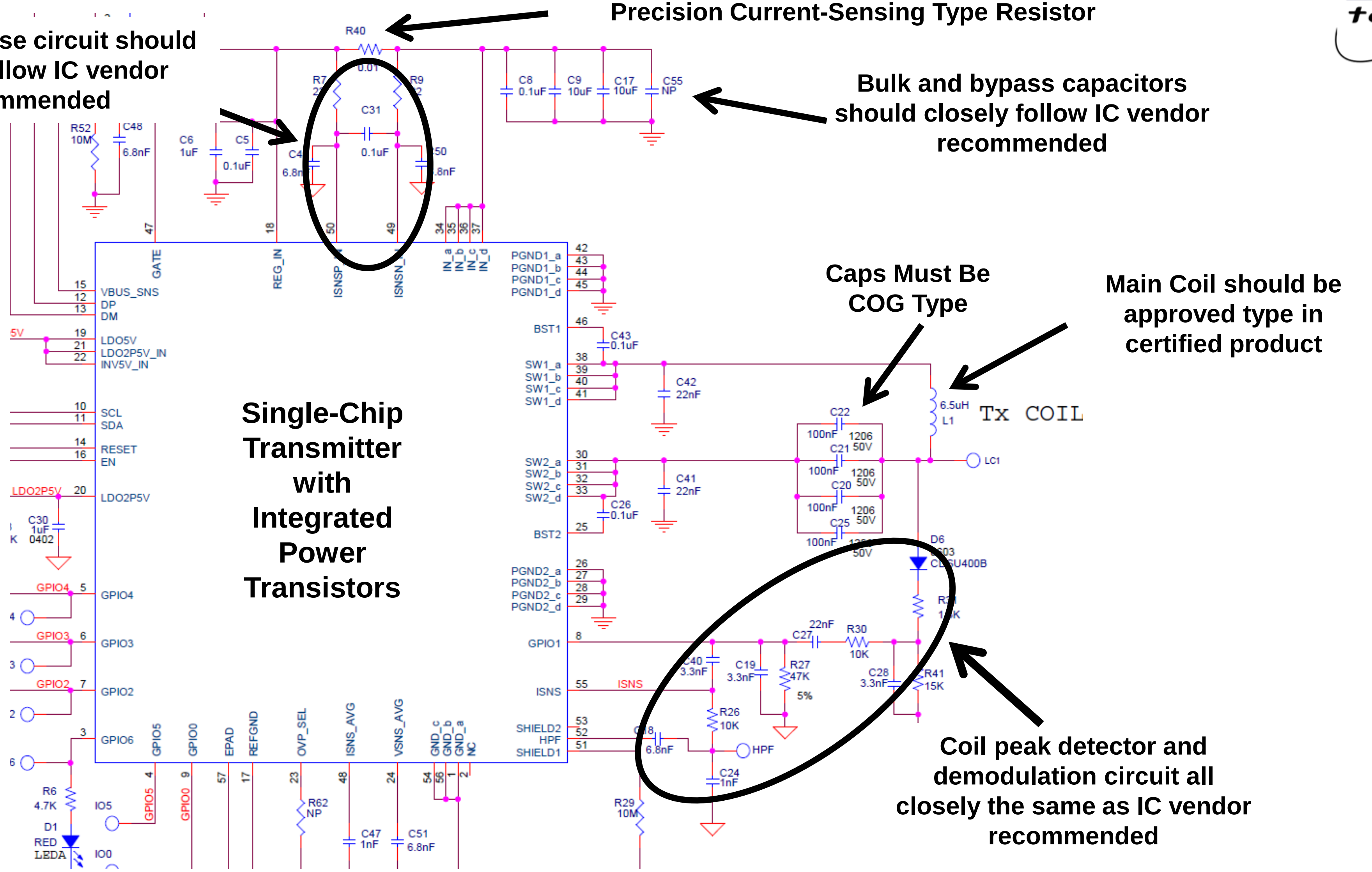
PTx Component Selection Guidelines (1)

- If the transmitter uses external power transistors for the bridge driver, these must be carefully and fully designed-in
  - IC vendor may specify gate drive characteristics, switching time, etc.
  - Typically the designer can choose the device on-resistance for the best cost decision
  - Passive components tied to the power transistors may need to be adjusted according to the IC vendor recommendations depending on the properties of the selected transistors
- Use a standard transmitter coil that is the same as defined for the selected WPC transmitter type and that has passed all of the WPC requirements. Alternative coils could have issues that should be checked carefully, such as:
  - Improper inductance value for the specified transmitter type
  - Higher than expected coil resistance (could cause FOD or Guaranteed Power issue)
  - Thinner than specified ferrite material (could cause FOD and/or Guaranteed Power issue)
  - Low quality ferrite material that could be lossy, become easily saturated, etc.
- COG capacitors in the power circuit are a must and should not be substituted. For example, using instead an X7R type in a Tx-A11 design will add about 400mW heat loss into the capacitors. This can cause FOD and Guaranteed Power problems and could cause failure of the capacitors. This is from the partial resonance in the LC tank making a big circulating current.

Component Selection Guidelines (2)

- If the transmitter uses an external current sensing resistor, this is very important for the FOD and other measurements. So a true current-sense type resistor should be used with the accuracy as specified by the IC vendor
- Bypass and "bulk" capacitors that on both the Transmitter and Receiver should not be made less than or different from the IC vendor recommendation. And if these are low-cost ceramic type, then the "derating" of the actual capacitance value should have careful engineering attention so that the effective capacitance value is the same as what the IC vendor recommends. (Note: The IC vendor may already have taken into account such derating assuming a particular type of capacitor is used.) Additionally, capacitors can make acoustic noise, and this can vary depending on the construction and material type of the capacitor.
- If there are any demodulation passive components in the transmitter or modulation components in the Receiver, the type and tolerance recommendation of the IC vendor should be followed. These may be critically balanced for best performance, and changes can cause unreliable communication issues between PRx and PTx.

Common PTx Circuit Implementation Issues

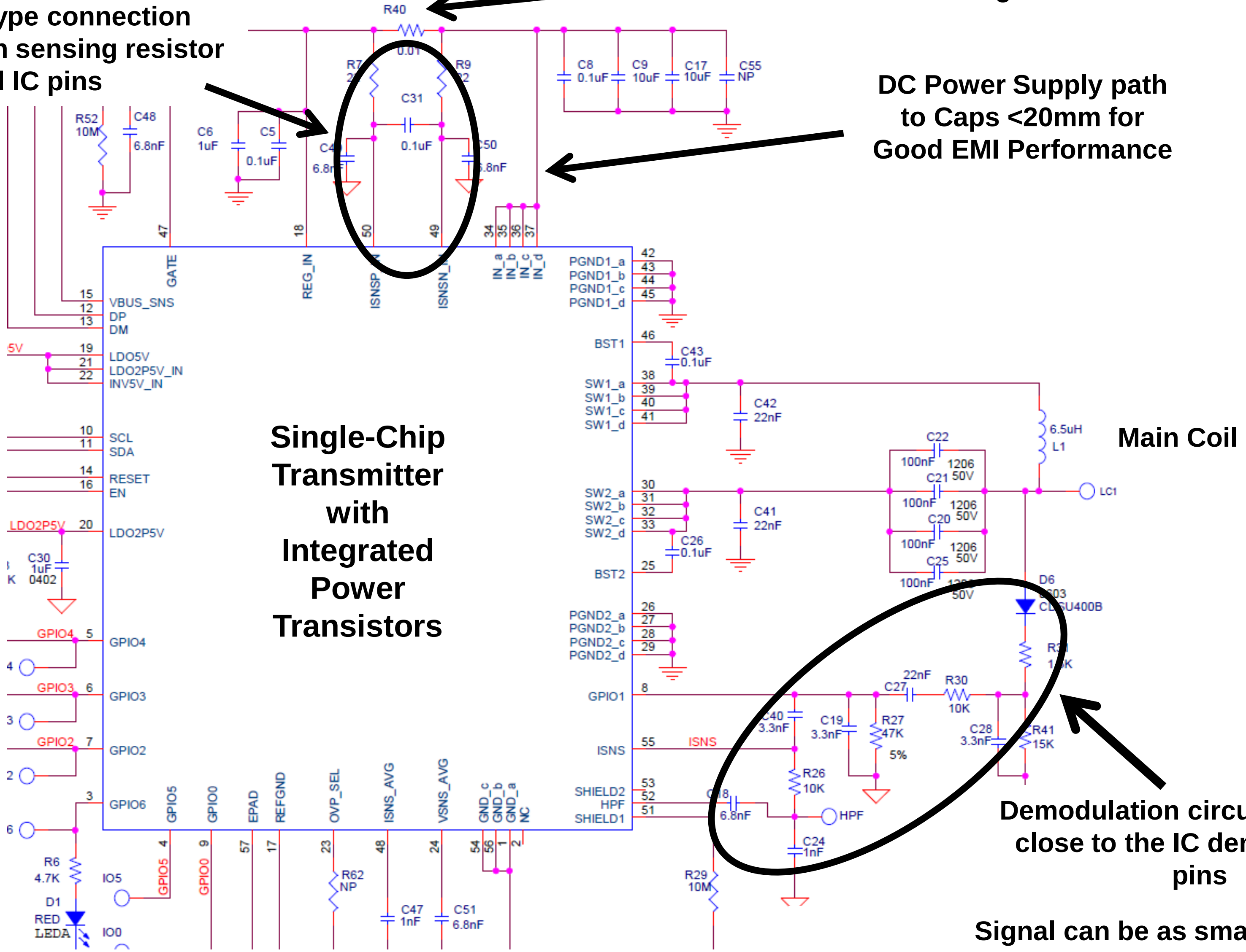


Example of PTx Circuit Layout Special Cases

Precision Current-Sensing Resistor

"Kelvin" type connection path between sensing resistor and IC pins

DC Power Supply path to Caps <20mm for Good EMI Performance



Demodulation circuit all placed close to the IC demodulation pins

Signal can be as small as about 30mVpp !

PTx Circuit Layout Guidelines

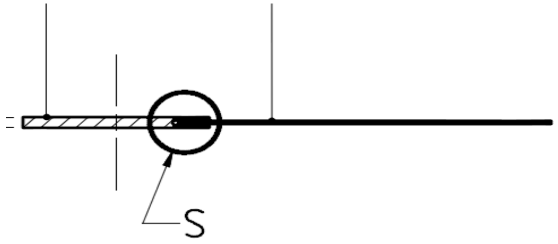
- Most applications require high power, high efficiency, good thermal performance, and low EMI. The circuit designer and layout designer should be careful to follow all of the normal rules for good design of these kind of issues. And they should note that because of the partial resonance that the circulating current can easily be 2x or more higher than the average DC current flowing in some paths of the system.
- The most common unexpected cause of an EMI failure is accidental series inductance between the power transistors and their supporting bypass and “bulk” capacitors. Even a wire as short as 1cm has enough inductance to cause a severe ringing in a power circuit. This type of failure will typically show up as a strong emission in the 30MHz – 100Mhz frequencies.
- If there is a signal diode for the purpose of recovering a demodulation signal on a Transmitter design, this diode should be placed near any other demodulation passive components which should placed very close to the IC demodulation function pins. The reason for this is that the demodulation analog signal at times can be as small as about 10mV, and so it is easy to lose this signal because of noise that is added from long layout signal paths.
- If there is an external current-sensing resistor in either the Receiver or Transmitter circuit, this should be connected to the device pins using a “Kelvin” style connection. In this method, the layout is such that no current flows through the two wires used to measure the resistor voltage. This is very important for accurate current measurement.

Worldwide Agency and Government Compliance

- WPC certification and specifications do not address worldwide requirements for EMI/EMC, efficiency, materials, etc. And these specifications can be strongly different depending on the country, or in cases, even depending on a smaller region inside a country. Designers must have good knowledge of all such requirements where they plan for their product to be sold.
- Examples (not a comprehensive list):
  - CISPR-22
  - FCC Part-15, Part-18
  - EN-303-417 (magnetic and radio emissions)
  - U.S.A. California "Green" efficiency requirements
  - Regional "Green" materials requirements for safety
  - Regional "Green" materials requirements for recycling

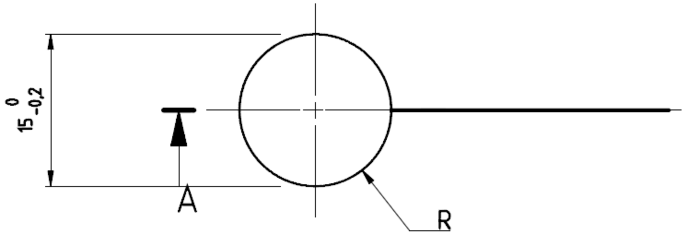
The Basic Idea of the FOD Test

- Three Reference Test Foreign Objects are Defined in Detail
  - Object #1: 15mm dia steel disk with integrated thermocouple
  - Object #2: 20mm dia aluminum alloy disk with integrated thermocouple
  - Object #3: 20mm dia aluminum foil disk with integrated thermocouple
  - Test frames and spacers are also defined for placing/holding test objects on PTx surface



Example Cross Section View

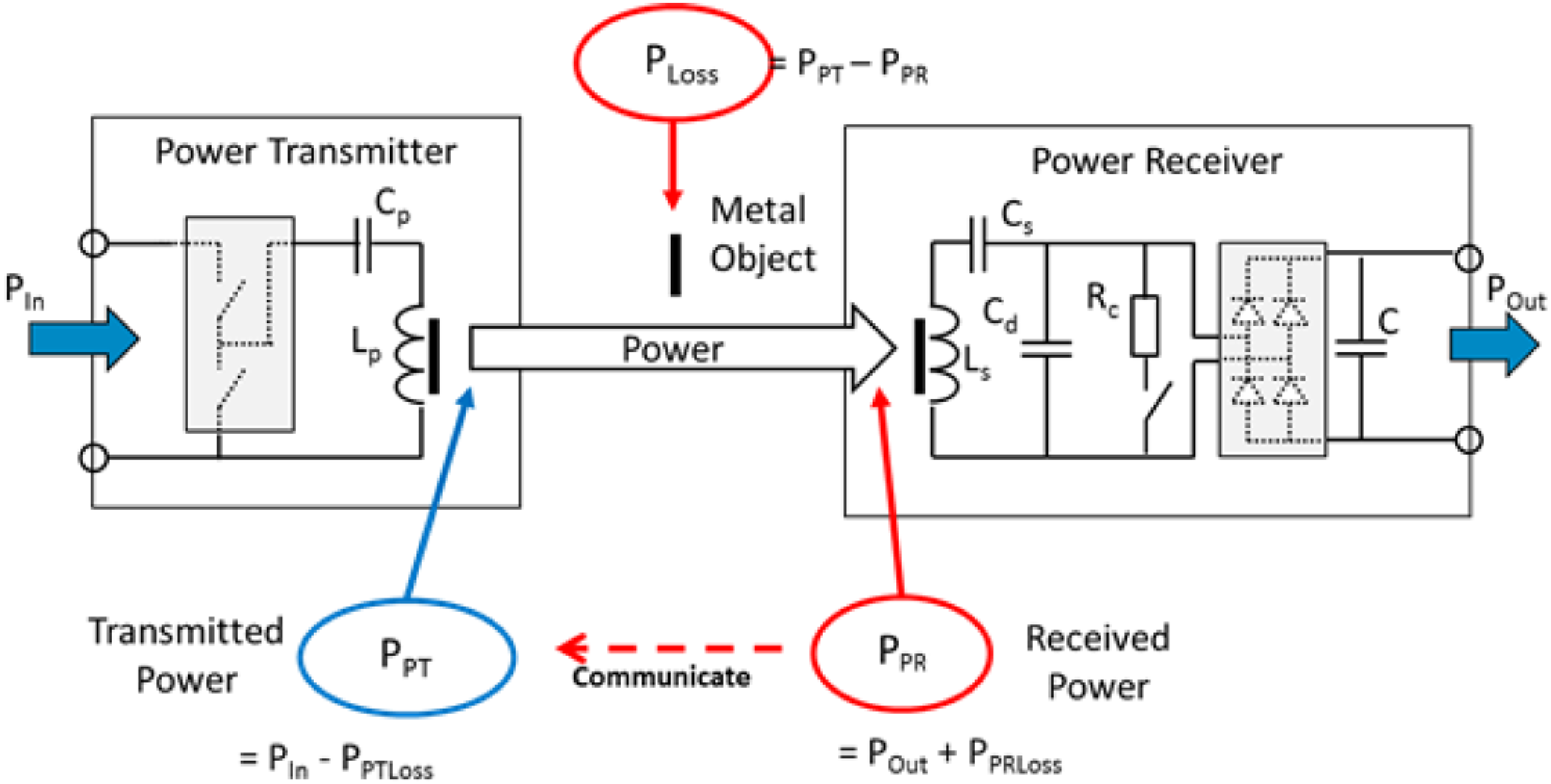
17.9mm dia
for comparison



Example Plan View 15mm dia object

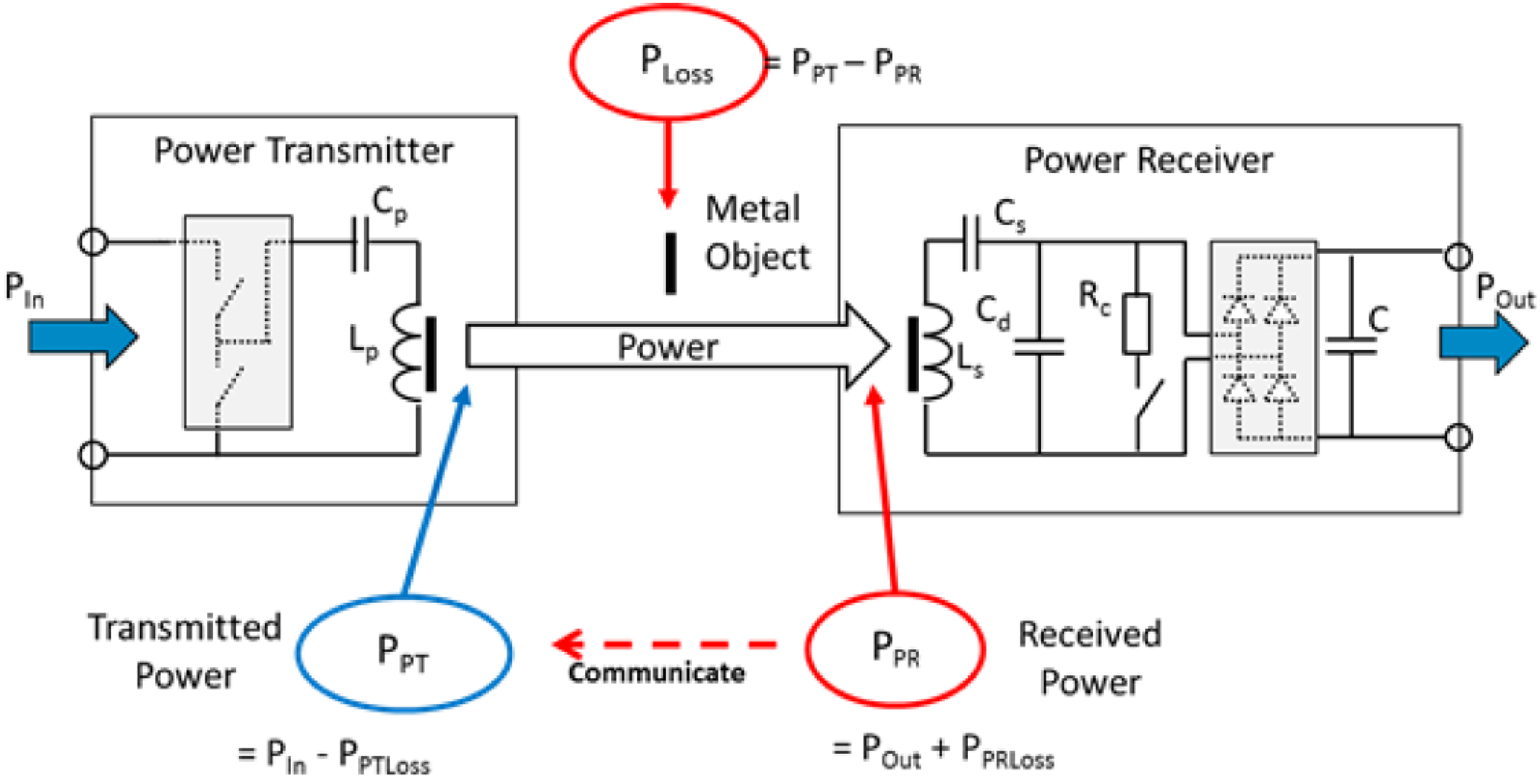
- Summary of Test Procedure - It is only about the heating of the test objects!!
  - Follow various specified placements and sequencing
  - If PTx refuses to go to power transfer with the object present, this is passing
  - If PTx terminates power transfer within various times/metrics, this is passing
  - If PTx continues power transfer, but object temperature remains below limit, this is passing
  - Pass if objects #1, #2 < 60-C heating and #3 < 80-C heating

Common Circuit Implementation Issues



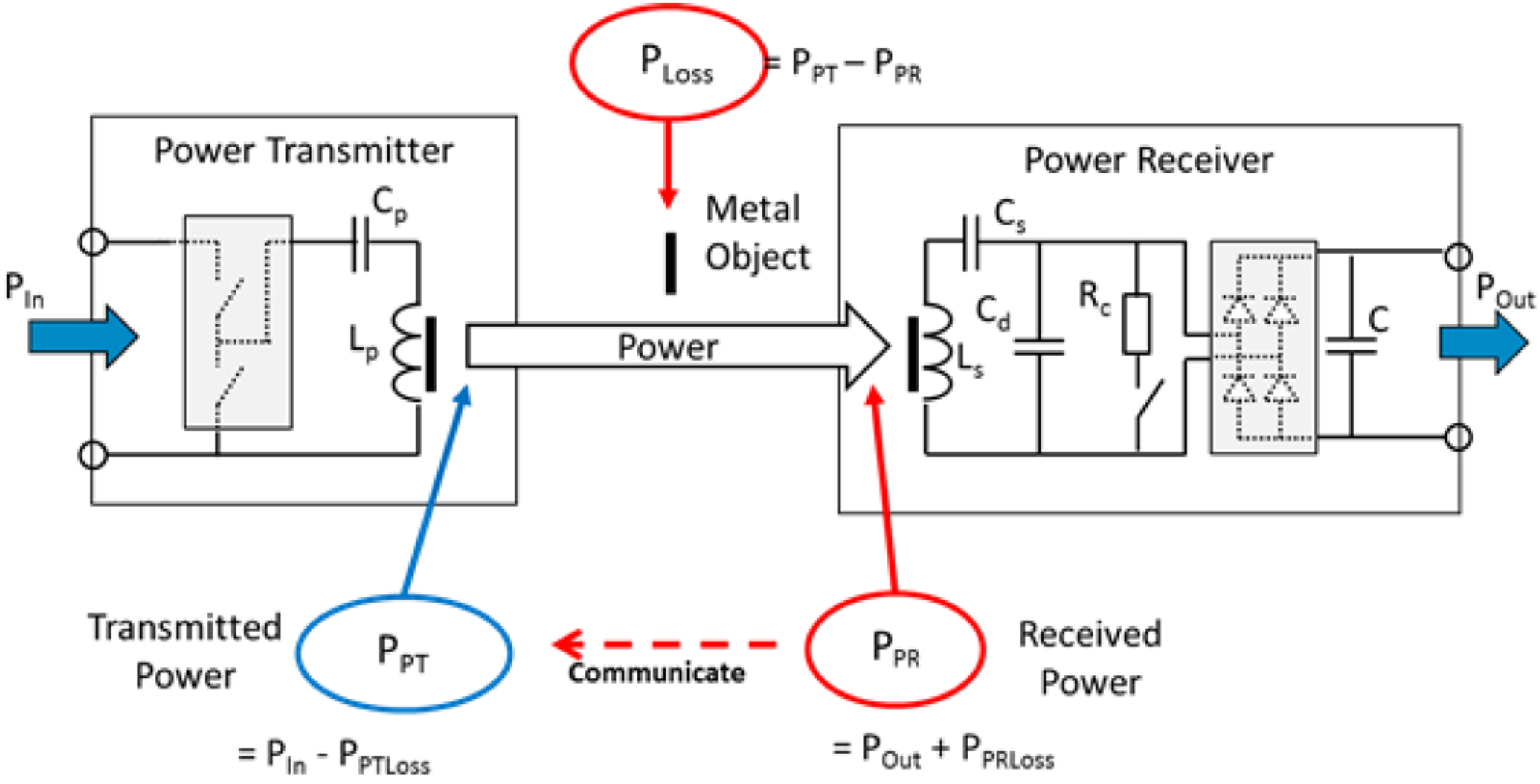
- Transmitter determines if there is an unexplained loss
  - Receiver reports Ppr as “Received Power”
  - Transmitter calculates Ppt-Ppr
  - If more power is lost than allowed, then FOD

Common Circuit Implementation Issues



- Receiver determines actual power available from PTx
  - Measure “Pout”
  - Account for all known Rx losses “Pprloss”
  - Determine power available at PTx coil surface “Ppr”

Common Circuit Implementation Issues



- Transmitter determines if there is an unexplained loss
  - Receiver reports Ppr as “Received Power”
  - Transmitter calculates Ppt-Ppr
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Q Measurement FOD Method

- Normally, for efficiency, the PTx has a very high “Q”, which is the Quality Factor. When the coil is very low resistance and losses in the PTx PCB, COG capacitors, and transistors is very small, then the Q-factor will be very high.

- When there is any loss of energy from the PTx coil such as by foreign metal, friendly metal, or power taken by the PRx, then this reduces the “Q” of the PTx.

- In the Q-Measurement method, the PTx uses information from the PRx to decide if the measured Q-factor on the PTx and with the PRx present is the amount expected.

- If there is too much foreign metal, the Q-factor measurement will be lower than expected, and so PTx will determine that there is an FOD case.

Adjusting FOD and Q-factor (if EPP PTx/PRx)

- For FOD, the final PTx implementation must be adjusted so that PTx can accurately determine all of its “known” losses. This calibration is typically done using a compliance checking tool such as Nok9, Micropross, or AVID. By knowing all of its known losses, PTx can determine if there is some unexplained power loss based on reported Received Power information from PRx.

- PRx must be calibrated to know all of its known losses and to take these losses into account when reporting the PRx Received Power value. To create some margin for reliable operation, PRx is required to “over report” more power received than is real. This extra margin prevents false FOD alarms because of device component variations or non-optimum placement of PRx on PTx.

- If the PRx is an EPP type, then it must be measured to determine the expected change of Q-factor on PTx when the PRx is present on PTx. This measured value is stored in PRx (after measuring carefully on test equipment following WPC procedures), and this value is reported by the PRx to the PTx.

- EPP type PTx also must be programmed with stored information as to the expected Q-factor of its coil surface when no foreign metal, PRx, or any other material that could affect Q-factor is present on the Tx power delivery surface. When PRx is present, if there is too much unexpected change of Q by the presence of PRx, then a foreign object is suspected.

Don’t Forget About the Power Supply !

- The power supply for the PTx is part of the system. It is important to work carefully with the PTx designer to choose a power supply that will not cause problems.

- If the power supply has some delayed step-response with load changes, this can corrupt communication packets and cause possible interoperation issues with PRx.

- Also, if there is any periodic noise such as around 2kHz in the power supply, this can make communication with small coil devices such as wearables unreliable.

- And if there is too much loss in the power supply wire or connector (especially USB power), PTx can have not enough power, and fail the Guaranteed Power tests.

- For WPC compliance testing, power supplies should be verified working properly and provided for <u>each</u> of the samples supplied to WPC for compliance testing.

Most Common Surprise Problems

IMPORTANT: Check for all of the things described on the following slides **before** sending the final product for official WPC compliance testing

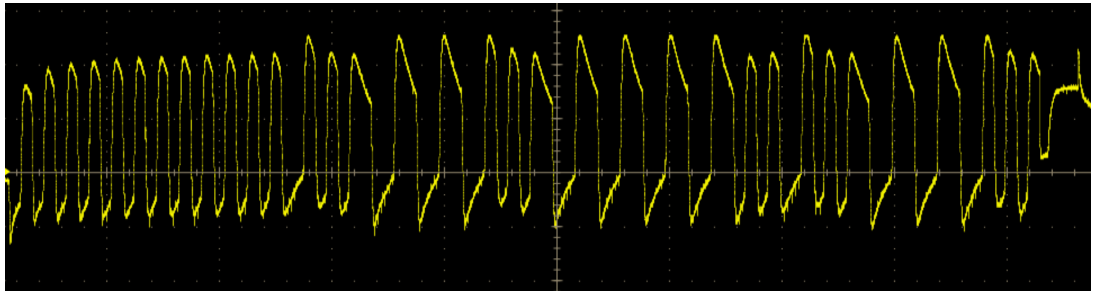
For either PTx or PRx, a pre-compliance test with a compliance testing type tool is a must !

- A large amount of usability testing is also very important !!
  - Try the new PTx or PRx with as many different partner devices as possible.
  - Try every kind of load on the PRx and all possible changes up/down of the load
  - Do these things in every kind of good/bad position, place/remove method the end-user may choose, etc. of the PRx on the PTx.
  - Study very carefully and fix any “bad spots” or bad end-user experience.

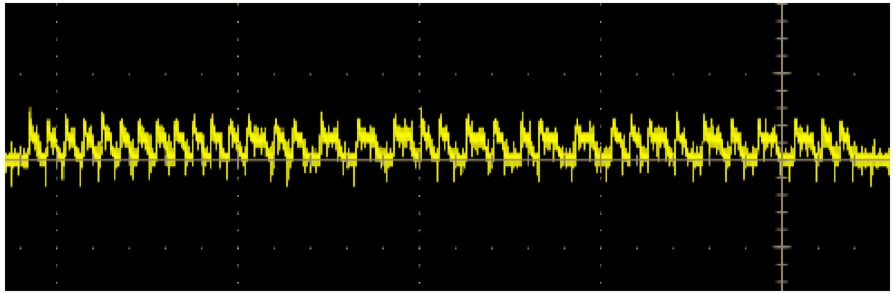
Problem: Failure to Communicate

Communication Signal Quality Problems

- PRx may not work reliably in some combinations of position combined with power level. When PRx has a very light load, WPC requires PRx have enough artificial load to prevent the communication signal from becoming distorted. Also, PRx must meet minimum “modulation depth” requirements in the specifications. Work with Receiver partner if this kind of problem is suspected or observed.
- PTx designs in the standards have previously passed Qi standards compliance, so problems in a new design are likely because of:
  - PCB layout problems
  - Power supply noise and/or power supply delay and response to load changes
  - Not following the rule for Z-distance spacer between coil and top surface of PTx



only about



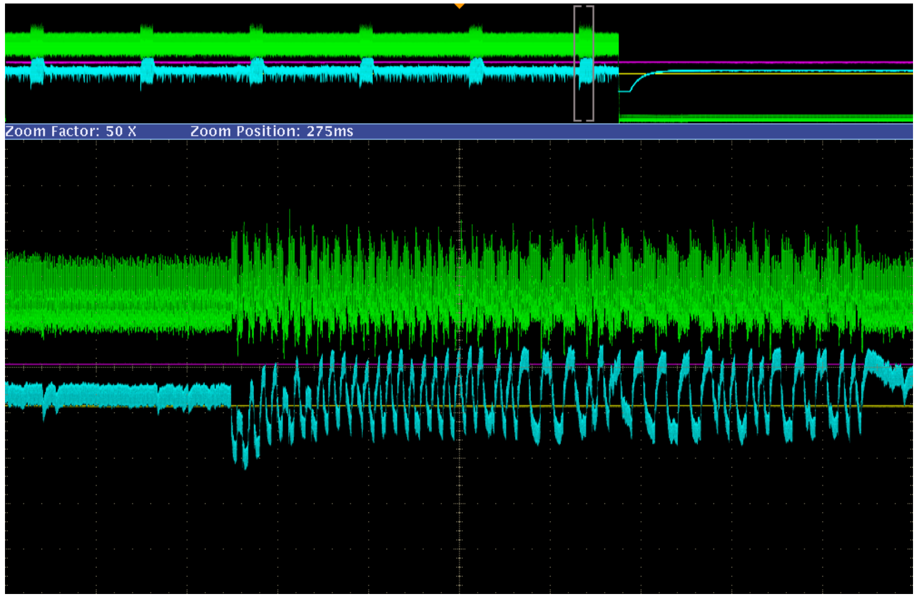
Demodulation Signal at PTx Side - good

Demodulation Signal at PTx Side – weak, distorted

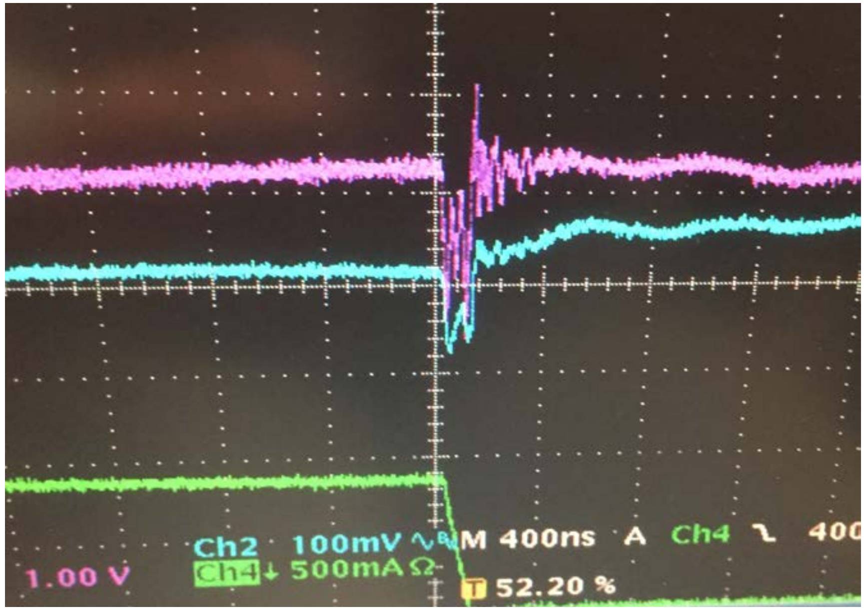
Problem: Failure to Communicate

Rectifier Misfire at Light Load

- When PRx has a very light load, the PRx synchronous rectifier can become confused about the right/wrong time to turn on and off. Watch for this kind of noise on the PRx coil, PRx rectified voltage, PTx demodulation signal, and/or PTx DC current. Discuss with your Receiver Partner if you see this kind of concerning signal under any conditions.



Continuous burst of misfire causes PTx to shut off.



Short burst of misfire when load suddenly becomes very small

Blue: PTx demodulation

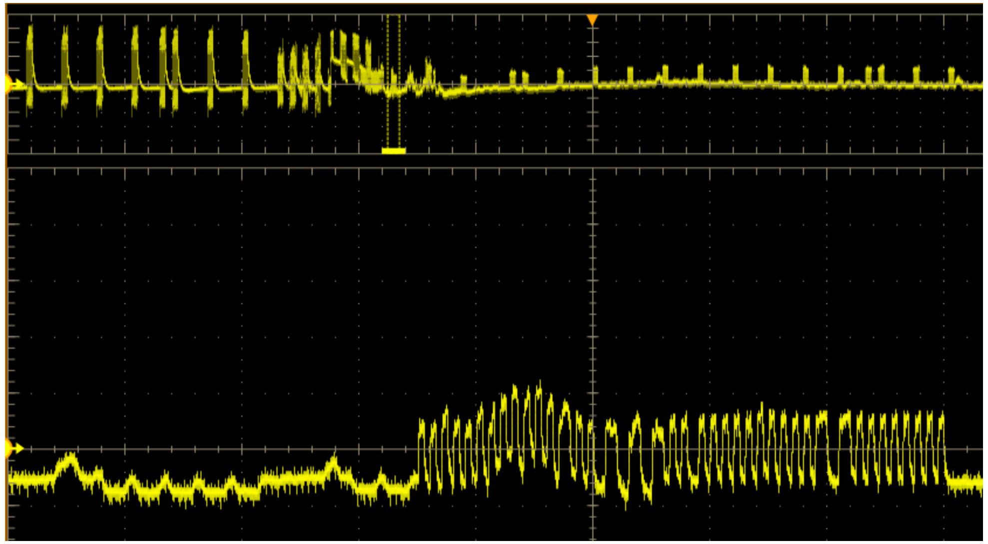
Green: PTx DC current

Problem: Failure to Communicate

“Load Reflection” at Light Load

- When PRx has a very light load, a small change in the client load current is a big change in the percentage of the total PRx power. This can disrupt ASK packets and if it happens for a long period of time (such as phone activity), PTx may shut off for lost communication. This problem is related to the entire system design of the receiver and should be discussed with the Receiver Partner if it is observed to cause problems. Some amount of this kind of packet corruption is normal and expected.

Short burst of phone or other receiver load activity corrupts about ten packets in this example



Problem: FOD or Q-factor Issue

We already talked about this!!

- However, if there are still problems with FOD or Q-factor, the most likely reason is too much loss and inefficiency in the PRx or PTx design. The Receiver or Transmitter Partner can adjust these values mathematically, but if the compensated loss is huge, then any small change will result in an FOD or Q-factor problem.
- Also with bad inefficiency, the Q-factor number will be very small. And with very small Q-factor numbers, it is more and more difficult for PTx to know FOD or not.
- With bad efficiency, it is also possible PRx or PTx can shut off for reason of over-temperature or overcurrent.

Problem: Failure of PRx to Reset

PRx Must Completely Reset Itself and Start Over if PTx Stops for Longer than 29msec

- Qi Specifications require that PTx can expect PRx to fully reset after removing power for only 29msec. It is important to check this!
- And it is important to know that the PRx supply voltage can follow any kind of crazy path at any time and any way – because we have no control of how the end-user may want to use the product.
- So in addition to the WPC requirement, it is also important to check that PRx always recovers no matter what crazy things you try to do with the supply voltage. The worst case is to continuously move across the region where the PRx system can no longer work and goes into the reset condition.

Problem: Singing Capacitors and Coils

Capacitors and sometimes PRx or PTx coils can make acoustic noise

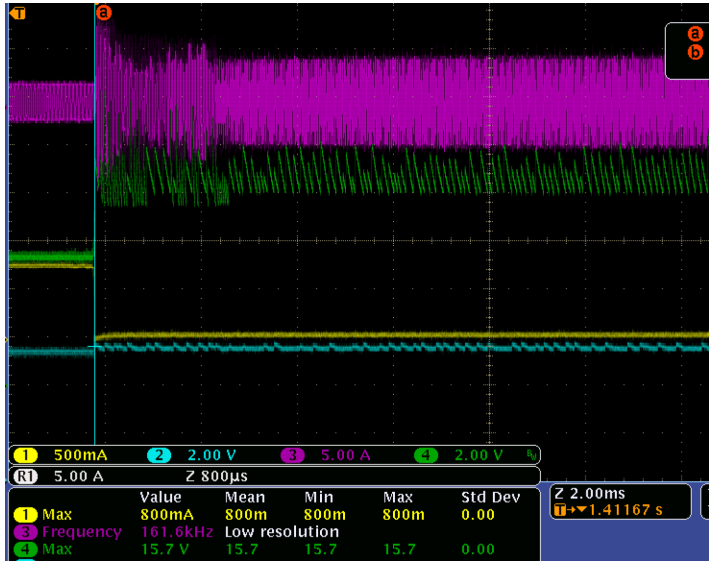
- The very small high capacity type ceramic capacitors can make acoustic noise from the busy electrical activity of the Rx. Sometimes a coil can also make acoustic noise, but in PRx it is mainly the large capacitors such as on the rectifier output. This noise may not be noticed until after products are already sold to end-users who may use the PRx or PTx in very quiet areas.
- So it is important to check a new PRx or PTx for any kind of acoustic noise that could cause an end-user complaint. Mainly the problem is fixed by choosing a different capacitor or coil vendor, or a somewhat different capacitor type. However, the mechanical design can also significantly make the acoustic noise worse or better.

Check PRx Self-Protection from Damage

Create "stress" conditions on PRx and verify that the device keeps itself safe from damage

Some end-user scenarios can create over-voltage, over-current conditions that could damage PRx. Verify that PRx system is always within safe limits.

1. PRx is operating at high power (such as 1-Amp load) and suddenly the load becomes zero. Rectifier voltage will quickly become very large.
2. PRx is moved slowly away from transmitter making PTx very high power. Very quickly, the PRx is placed back into the best possible coupling on the PTx.
3. PTx is operating at high power. Suddenly the PRx being used is replaced with a different PRx which is the one being tested.



Example where load suddenly becomes small. Check the PRx coil voltage, rectifier voltage, temperature, and any high currents all stay in safe limits until PTx can shut off power and fix the problem.

Thank you