Variable Position Wireless Power Transmitter through Multiple Cooperative Flux Generators

Joshua Schwannecke

Advanced Technologies Group

Fulton Innovation

Outline

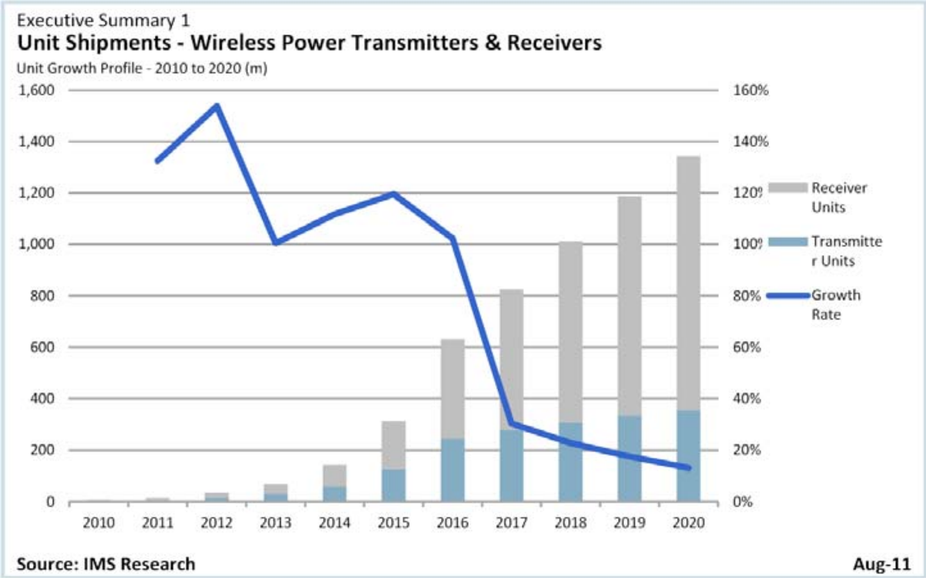
- Wireless Power System Requirements
- Current Implementation
- Improvements with Cooperative Flux Generators
- Validation of Concept
- Results
- Conclusion

Introduction

Fulton Innovation

- 10+ years experience in Wireless Power
- Technology development, licensing, and consulting on Wireless Power
- Founding member of and Key Contributor to Wireless Power Consortium
- Wholly owned subsidiary of Alticor, parent of Amway

- Wireless Power expected to grow in consumer devices in next ten years
  - Wireless Power Consortium's Qi™ standard addresses interoperability up to 5W



[1] "The Growth Potential for Wireless Power & Charging – 2011", IMS Research, Aug. 2011

Wireless Power System Goals

- More convenient than conventional "wired" power systems
  - Easy to initiate power transfer
    - Ideally works at any location
  - Readily available charging locations
    - Convenience realized through interoperability standard (Qi^{TM})
- Minimized power loss
  - Low loss in transmitter/receiver components
  - Minimal energy lost in unintended objects

Current Implementations in Qi^{TM}

- Concept: transmitter generates flux, receiver converts to usable power, up to 5W
- Many transmitters, two major themes
  - Array of many coils, used cooperatively or independently
    - Can be easier to locate charging area
    - Many coils can be expensive, complex to manufacture
  - Single coil with positioning assistance
    - Simplest design
    - Additional requirements to locate charging area

B1 coil

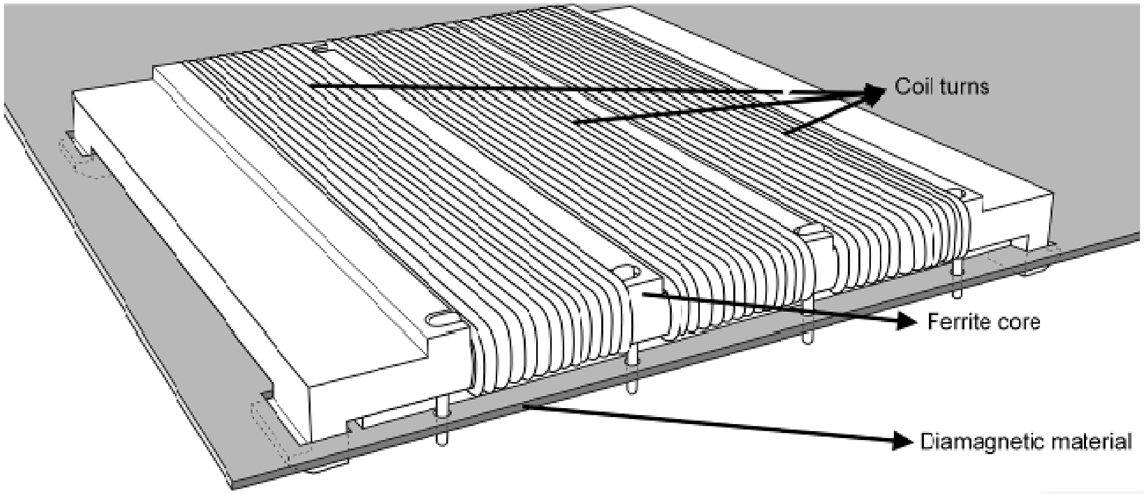
A1 coil

Cooperative Flux Generators

- Movable flux generating region
- Coupling from transmitter to receiver sufficient
  - k>25% suitable for Qi™ power and communication
- Multiple coils selected at given time
- Can be extended in each direction arbitrarily long

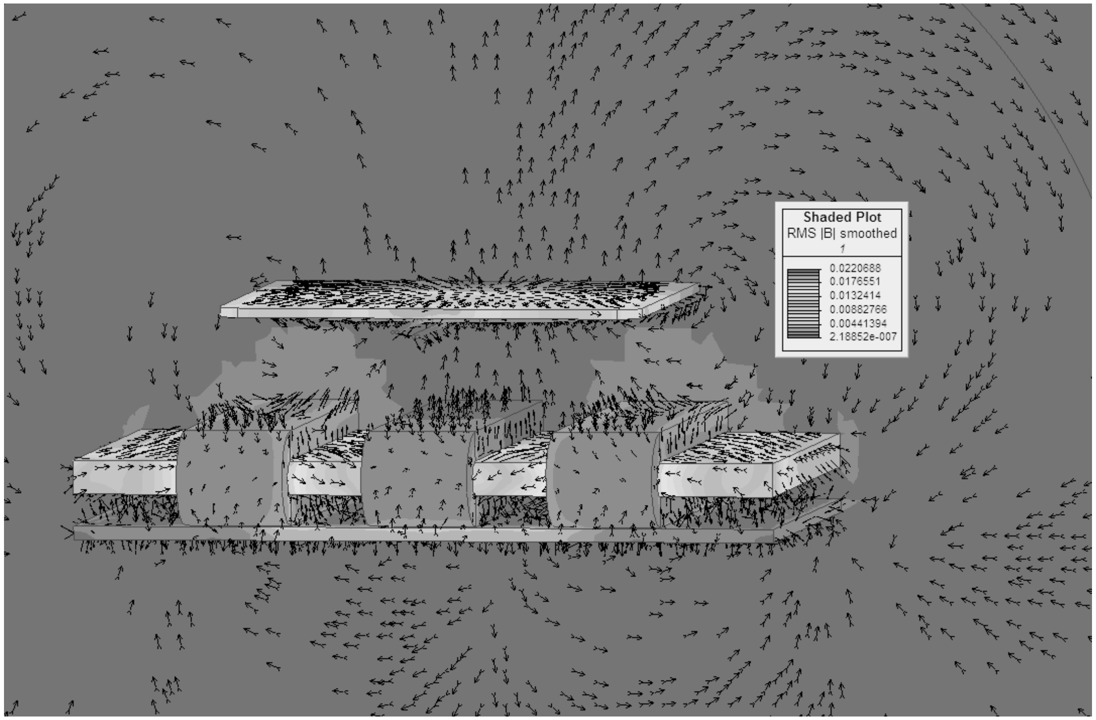
Theory of Operation

- Coils operated in tandem
  - Coils are coaxial on high permeability core
  - Coil current driven out of phase
    - Most flux in core cancels
  - Coils with current in opposite direction have a flux region between that can link to a receiver coil
- Diamagnetic layer beneath array to reduce flux path



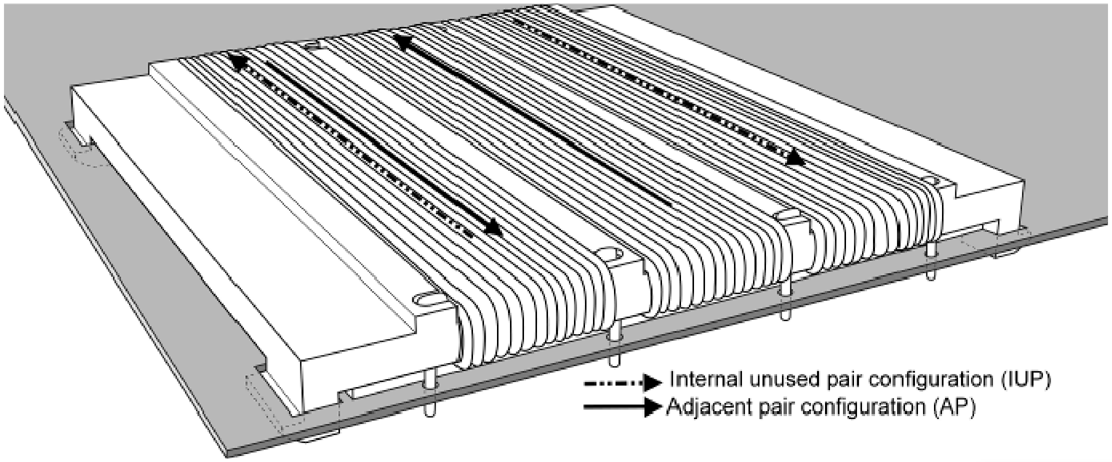
Finite Element Analysis

- Outer two coils driven out of phase
- High flux between transmitter coils
- Less flux below diamagnetic layer
- Lower flux in core
- High coupling between transmitter coils, receiver coil



Operation in System

- Two configurations
  - Internal Unused Pair (IUP)
    - Outer two coils of a group of three selected
    - Current in first coil inverse of current third coil
  - Adjacent Pair (AP)
    - Two adjacent coils along array selected
    - Current in first coil inverse of current in second coil
- Pair of coils together are treated as primary coil array (PCA) in transformer
- Automated control system tests each pair and selects pair with best coupling



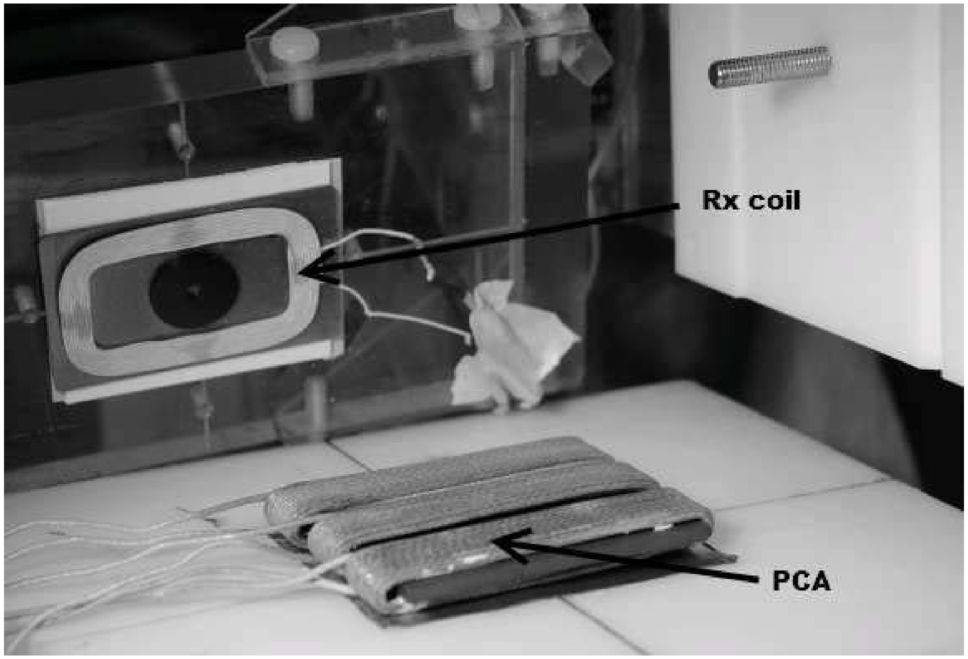
Validation of Concept

- Must be compatible with Qi™
  - Must transfer guaranteed power to 4 reference receivers
  - Must have k > 0.25 with Reference Receiver A [2] to meet guaranteed power level
- Validation procedure
  - Measure k at each position offset over each coil configuration
  - Superimpose coupling maps to understand total system area of sufficient coupling

[2] System Description, Wireless Power Transfer Volume I: Low Power Part 1: Interface Definition, Wireless Power Consortium v.1.0.1, 2010.

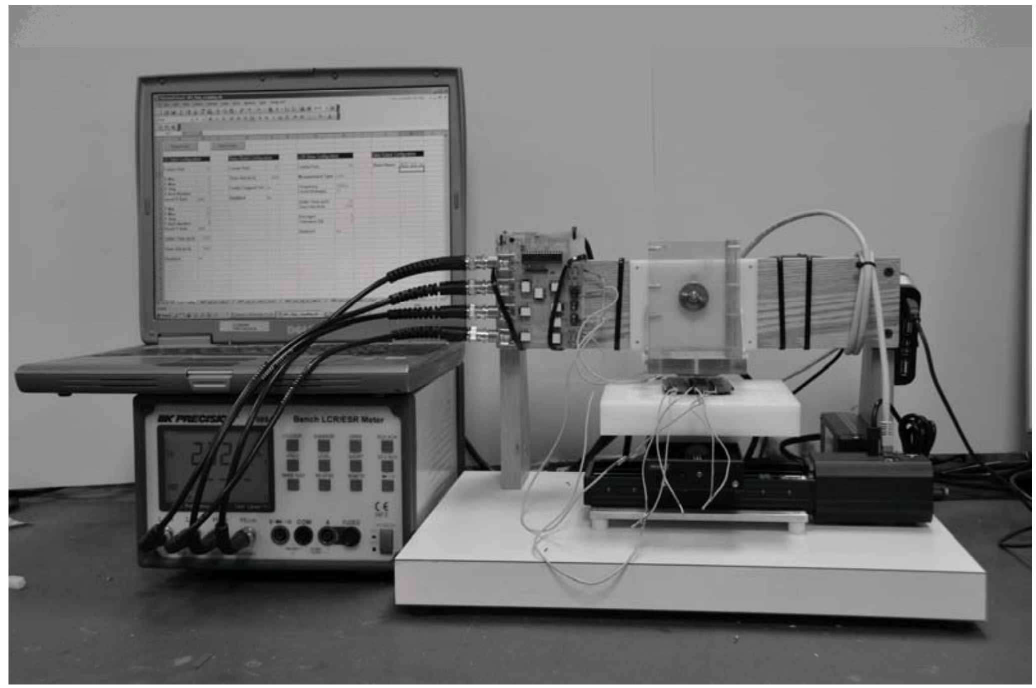
Experimental Setup

- WPC Reference Receiver A used as receiver (Rx)
- PCA is 3 TX coils coaxially wound around 2.5mm NiZn ferrite tile (Fair-Rite™ Mtl 44)
- TX coils 20 turns of 105/80μm litz
- PCA dimensions:
  - 53mm x 53mm
- Coil center spacing:
  - 18.67mm
- 0.1mm copper layer below PCA coils



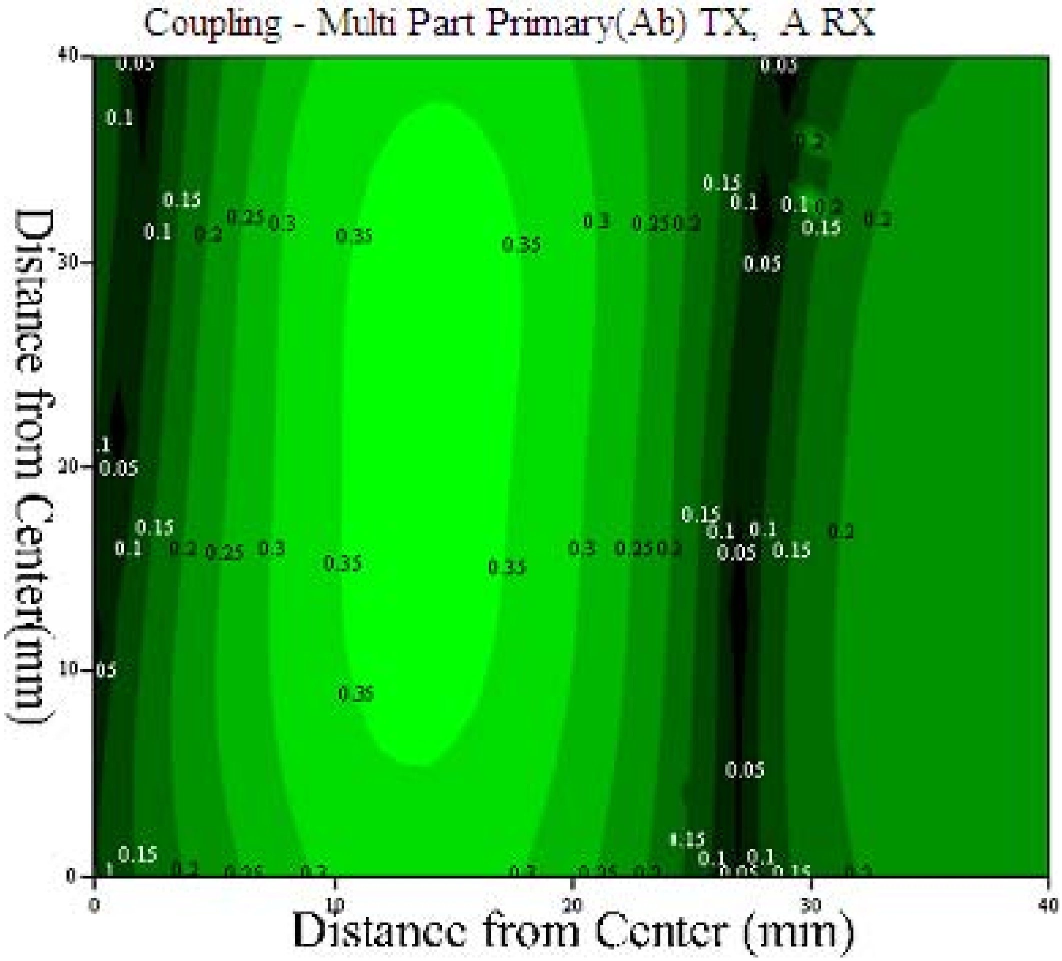
Coupling Mapping

- Rx and PCA mounted to numerically controlled positioning system
  - Rx mounted 5mm above PCA
  - Offset +/- 20mm X, +/- 20mm Y, 1mm step
- Coupling (k) calculated at each point
  - Primary (PCA) inductance, Secondary (Rx) inductance, and Mutual inductance between Rx and PCA measured successively
- Mapping done for both IUP and AP PCA configurations



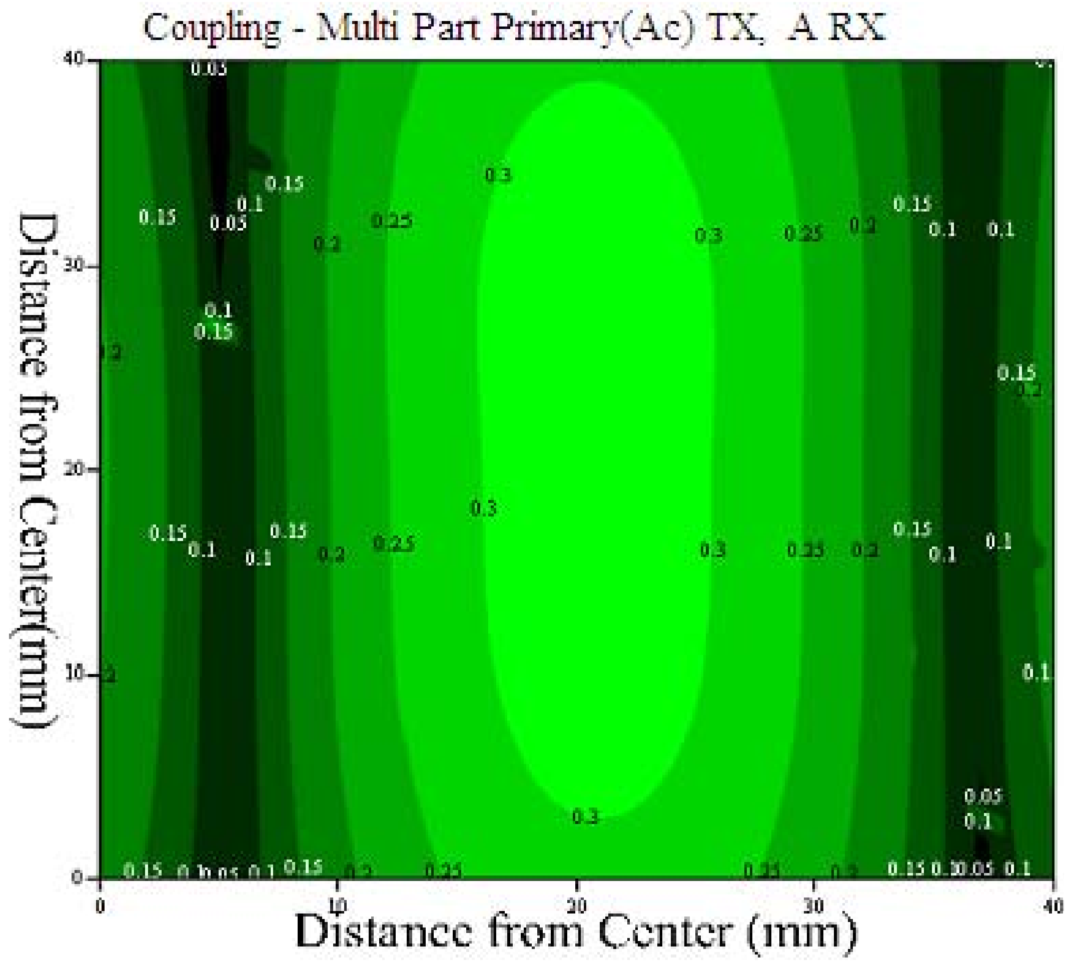
Coupling Map - AP

- Peak k > 0.35
- Area of k > 0.25:
  - X:
    - 5mm to 23mm from left edge
    - +/- 9mm from line 6mm left of horizontal center
  - Y:
    - from 0mm to 40mm
    - +/-20mm from vertical center



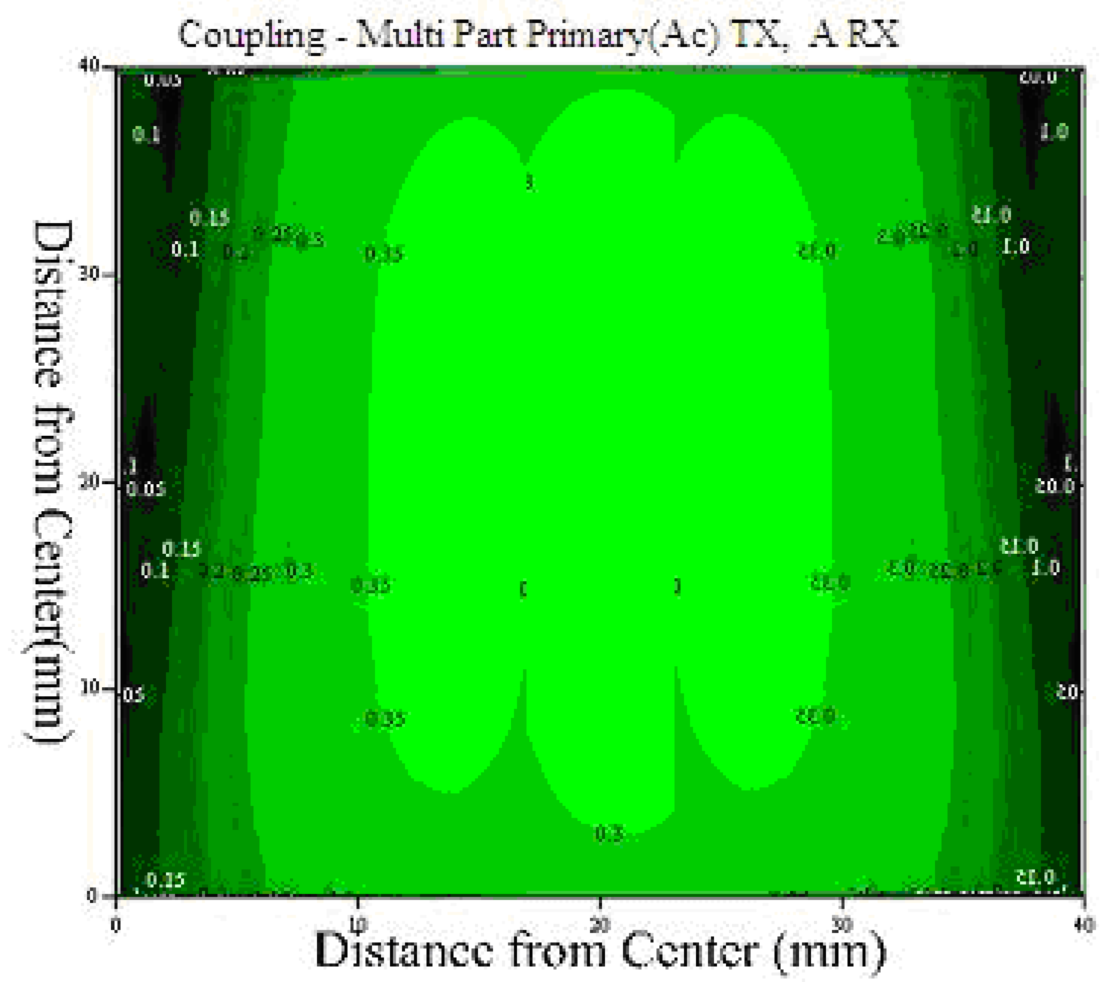
Coupling Map - IUP

- Peak k > 0.30
- Area of k > 0.25:
  - X:
    - +/- 7mm from horizontal center
  - Y:
    - from 0mm to 40mm
    - +/-20mm from vertical center



Coupling Map - Composite

- Area of k > 0.25:
  - +/-15mm from horizontal center
  - +/- 20mm from vertical center
- Additional Coils placed in horizontally would extend area indefinitely
- Free positioning achieved over area 40mm wide, with arbitrary length



Conclusions & Next Steps

- Arbitrarily long free positioning achieved
- Compatibility with WPC Qi^{TM} verified
- Fewer coils used than in other array methods
  - Fewer power electronic components needed for control
- Coaxially wound coils simpler to manufacture than other arrays
- Multiple coils engaged in each direction could adapt to larger Rx coils
- Could be extended to X & Y with orthogonal windings