Wireless Charging

Last updated 3/28/24

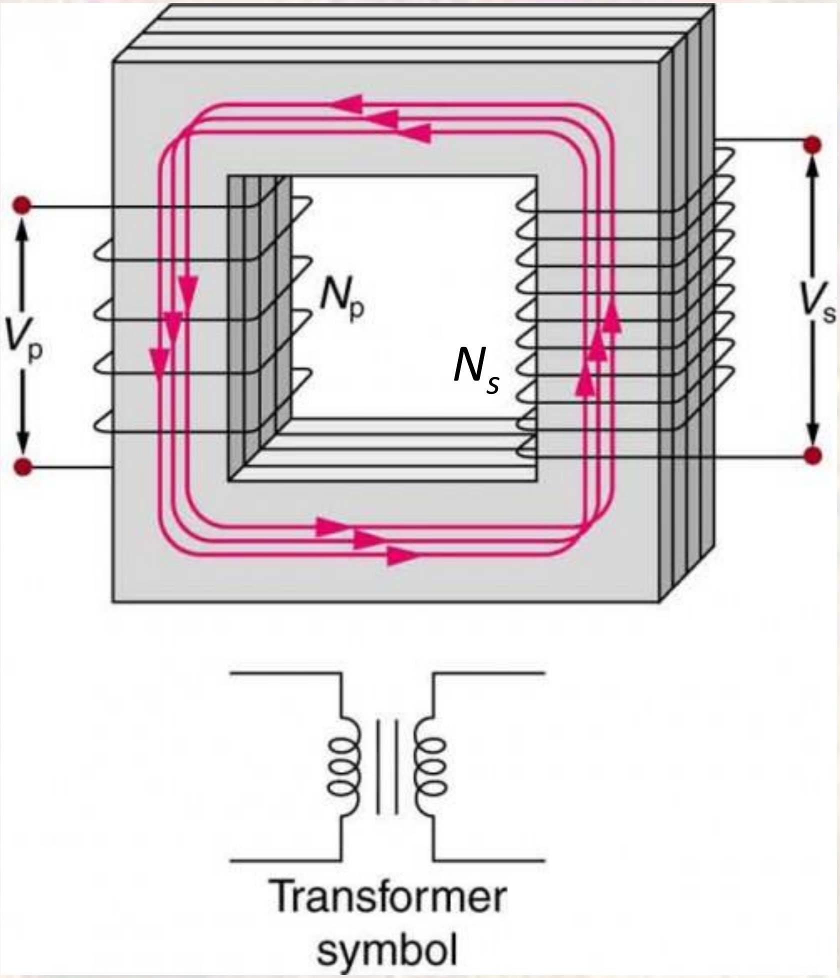
Wireless Charging

- Transformer

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

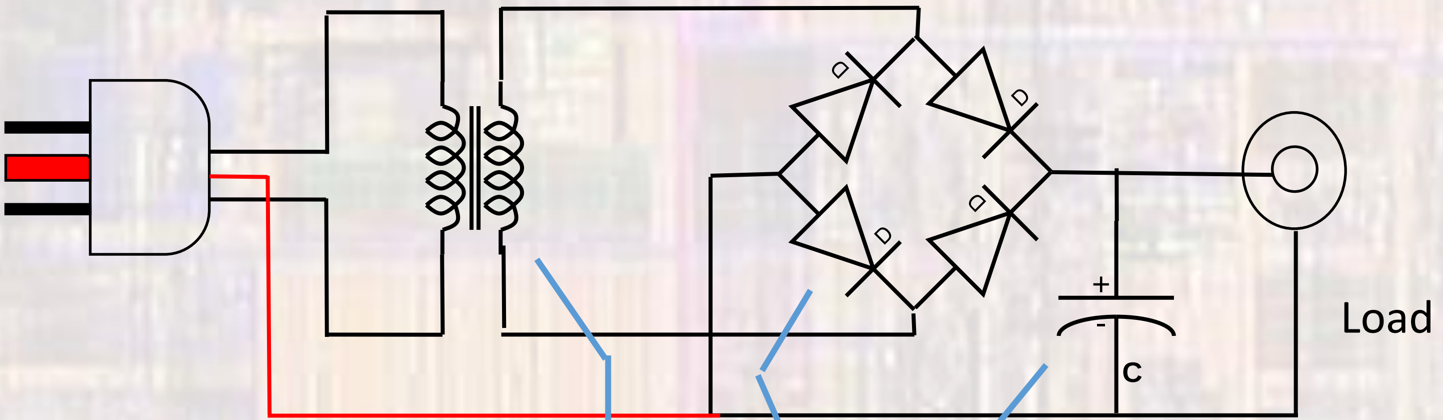
$$\frac{V_s}{V_p} = \frac{I_p}{I_s}$$

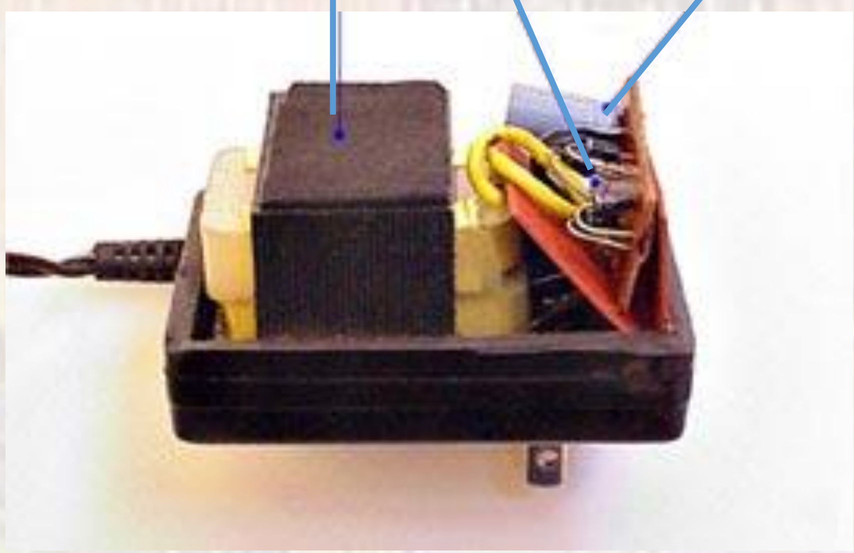
$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

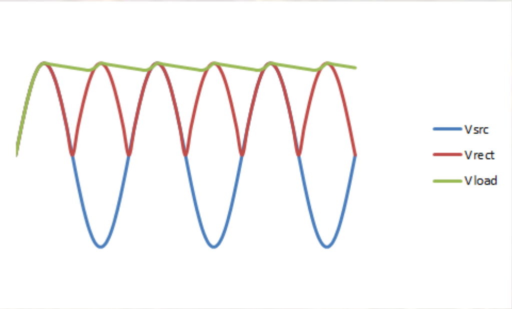


Wireless Charging

- Power Supply

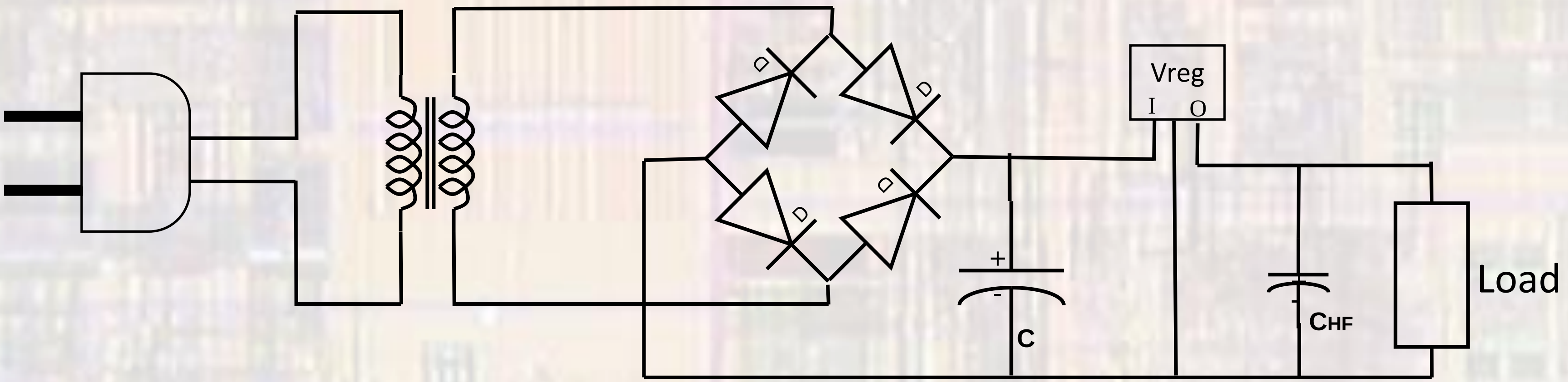






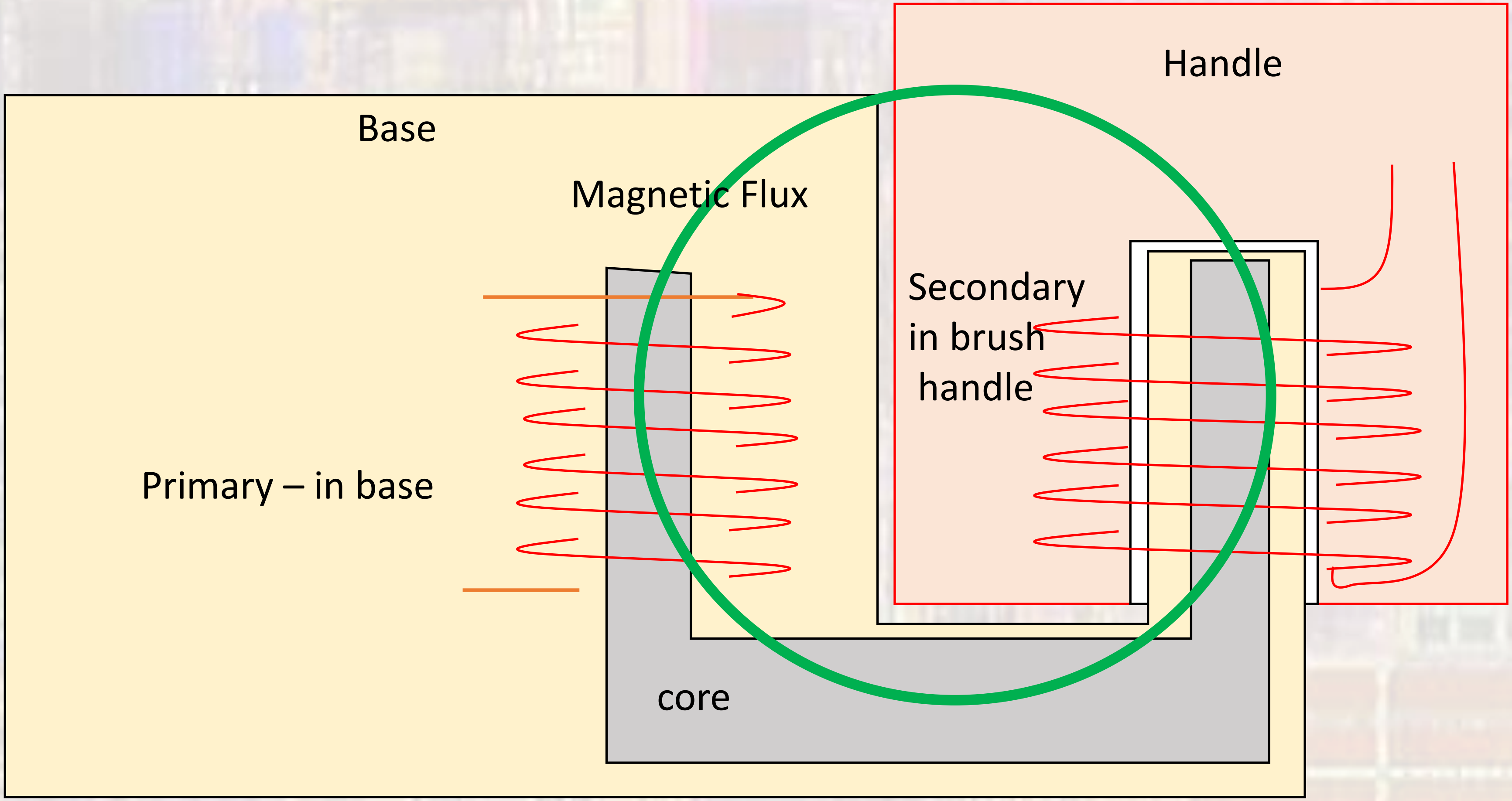
Wireless Charging

- Power Supply
  - Regulated supply



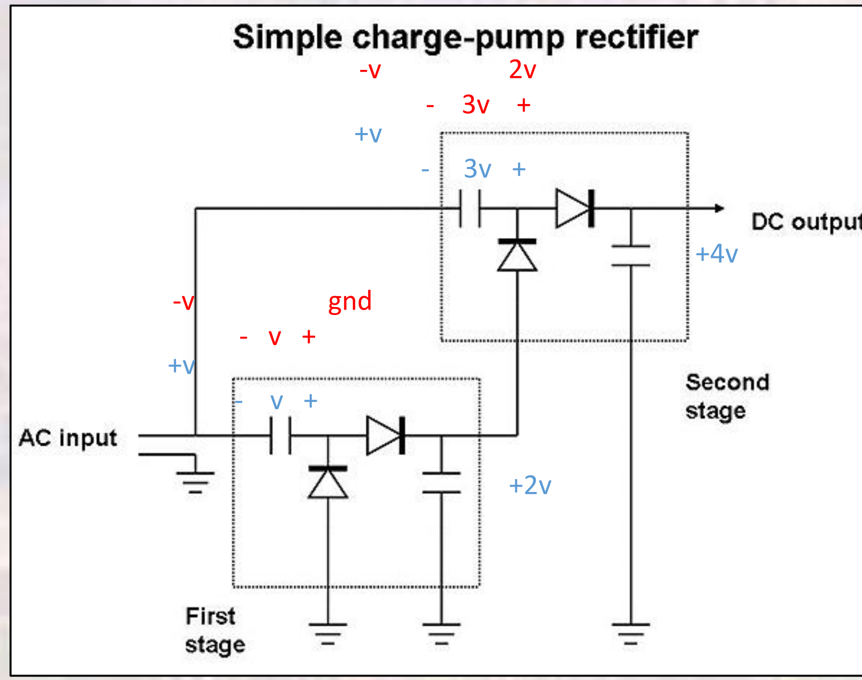
Wireless Charging

- Toothbrush
  - Handle placed on pedestal



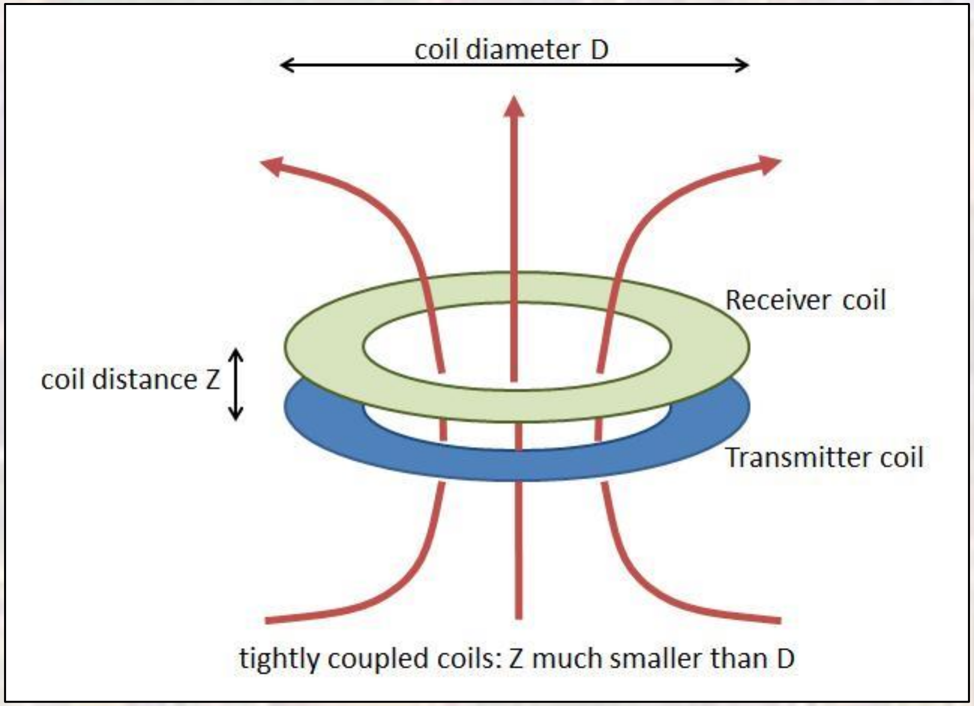
Wireless Charging

- Toothbrush



Wireless Charging

- Inductive Charging



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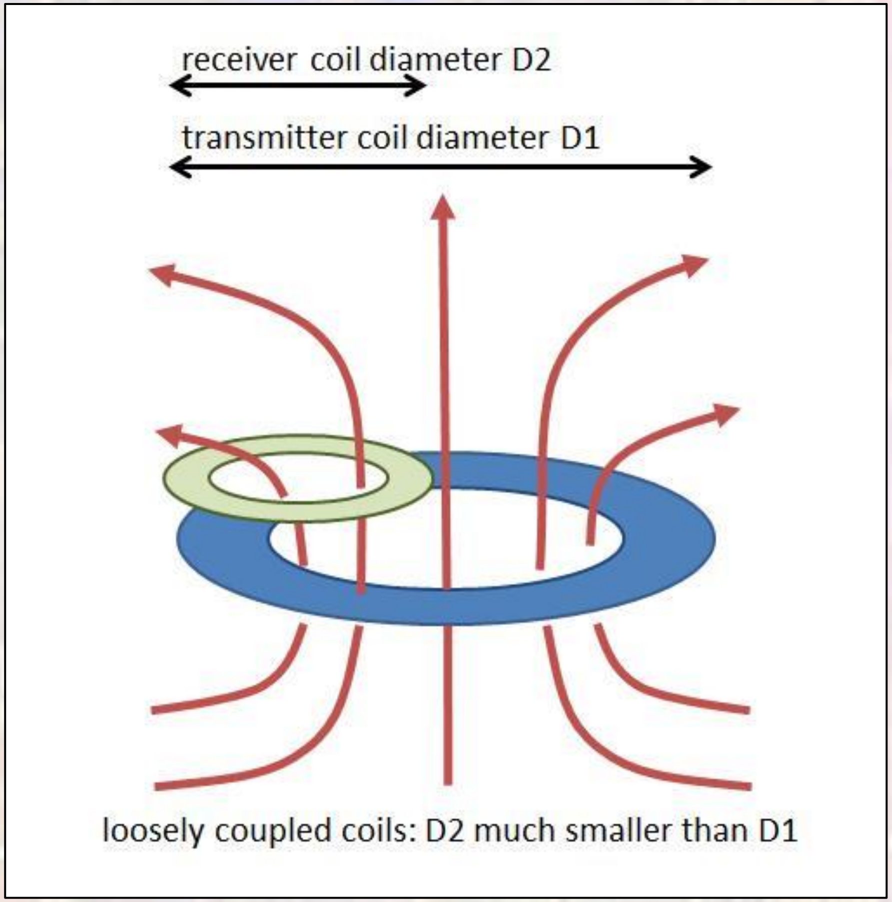
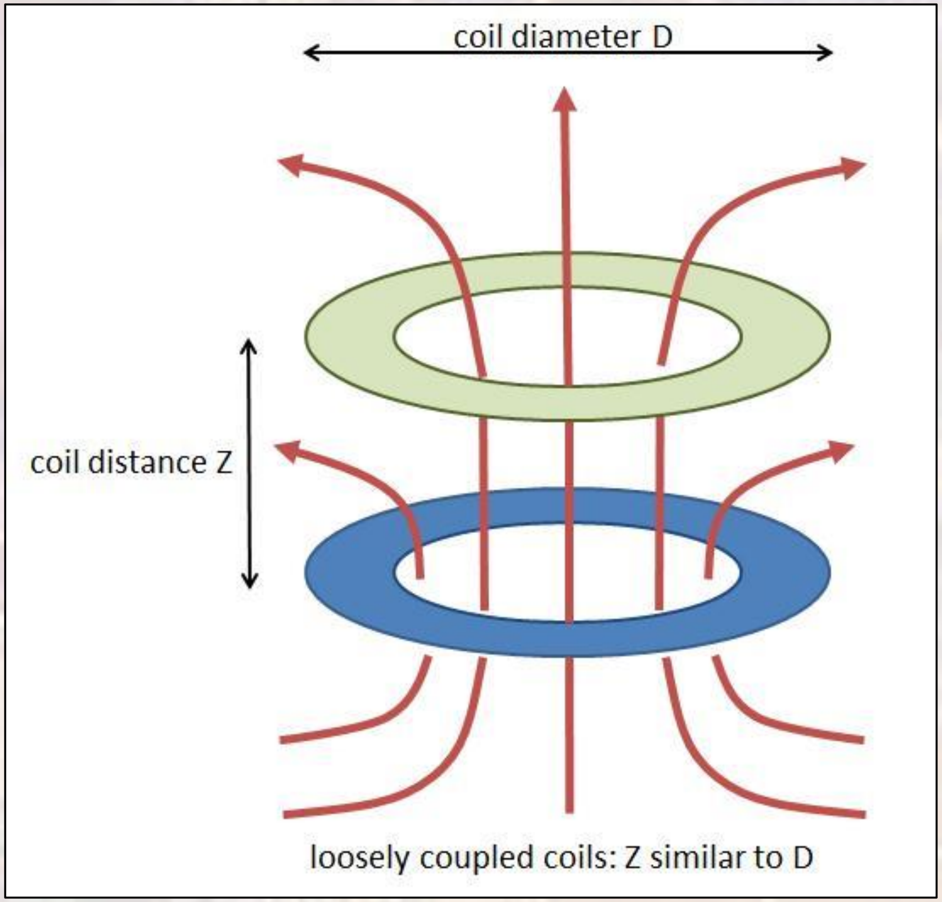
Wireless Charging

- Inductive Charging





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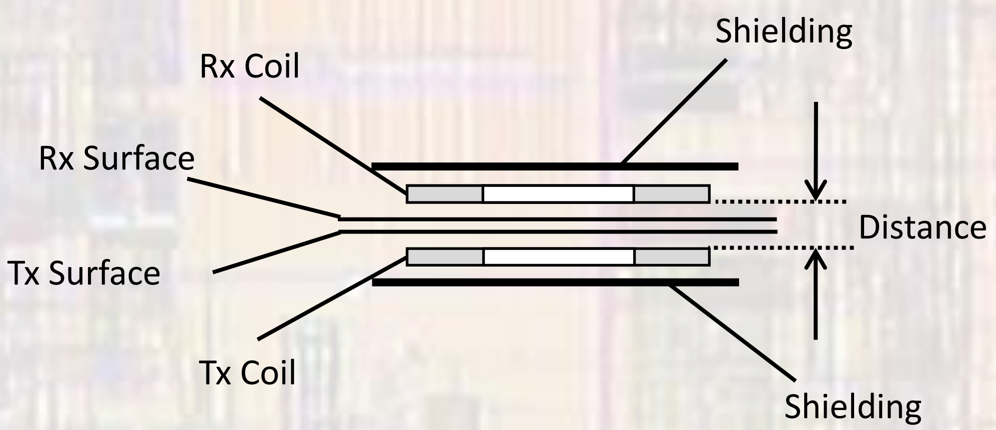
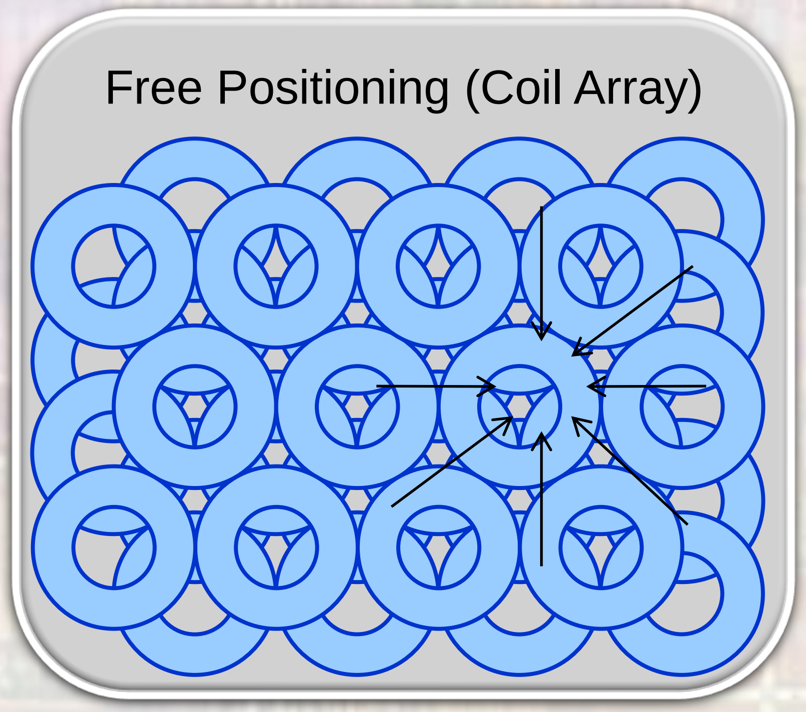
Wireless Charging

- Maximize Coupling
  - Choose appropriate dimensions of coils (matching size)
  - Keep the distance between coils small (flat interface surface)
  - Add magnetic permeable material (shielding)
  - Aligning the coils



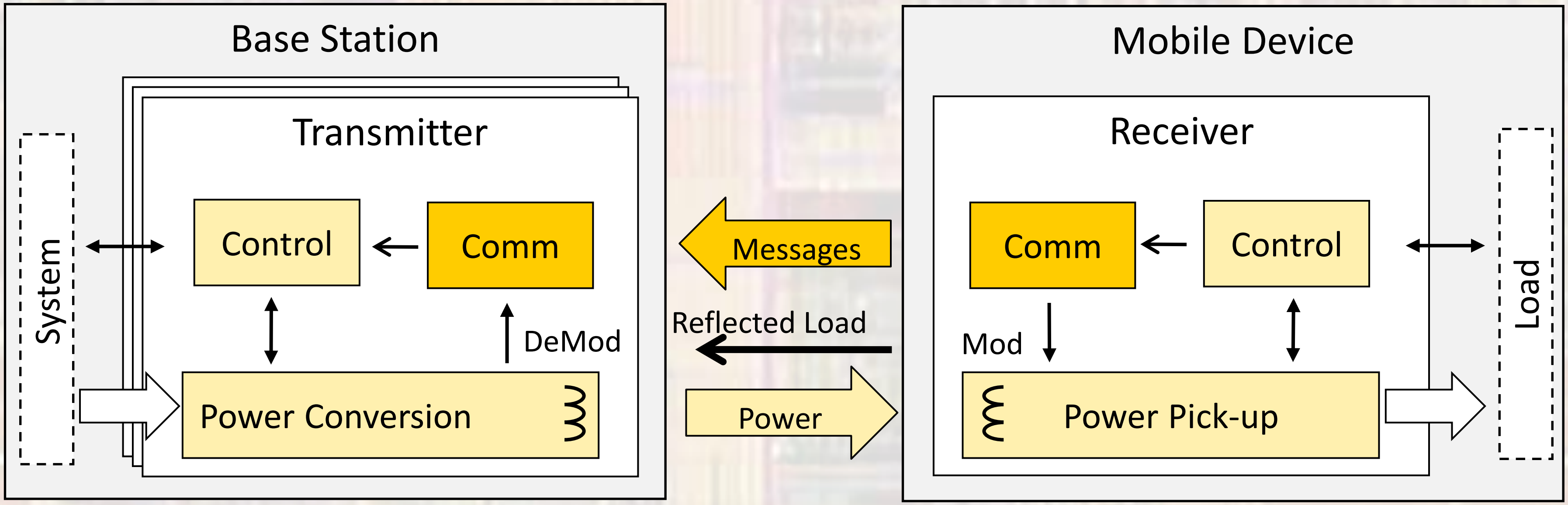
Wireless Charging

- Maximize Coupling
  - Fixed Positioning
  - Free Positioning
    - Switched array of coils
    - Self selecting?



Wireless Charging

- Control / Communication
  - Base
    - One or more transmitters
    - Control system to manage transmitted power
  - Device
    - Receiver to convert power to a usable form
    - Feedback to base station to control transmitted power



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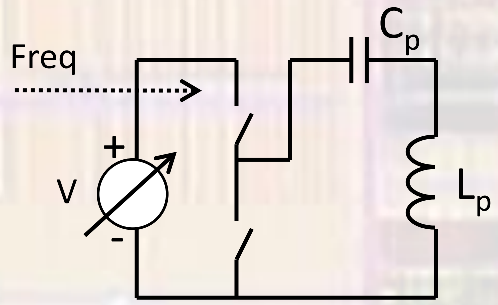
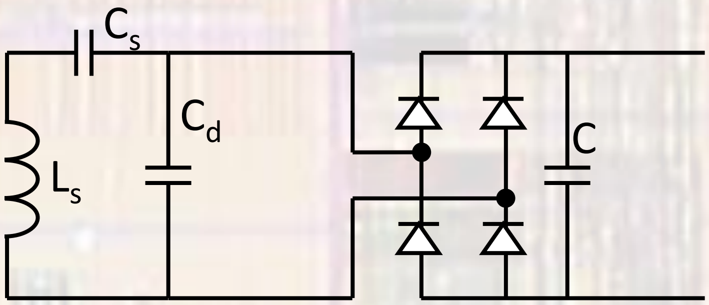
Wireless Charging

- Transmit Power Generation
  - Transmit coil
  - Half bridge inverter
  - Controlled by
    - Switching frequency
    - Applied voltage



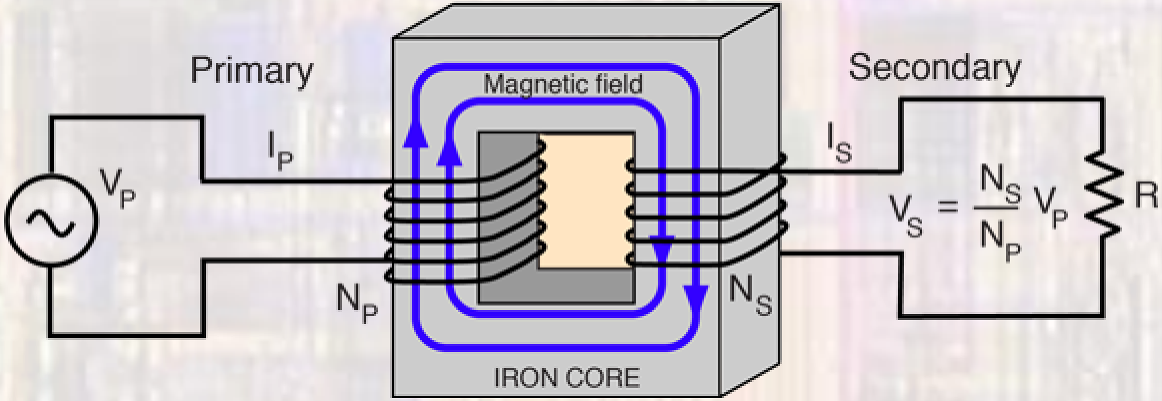
Wireless Charging

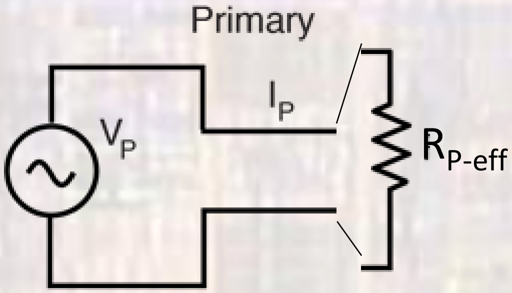
- Receive Power Harvesting
  - Receive coil
  - Full wave rectifier
  - Resonant series capacitor (efficiency)
  - Parallel resonant capacitor (detection)



Wireless Charging

- Effective Primary Resistance

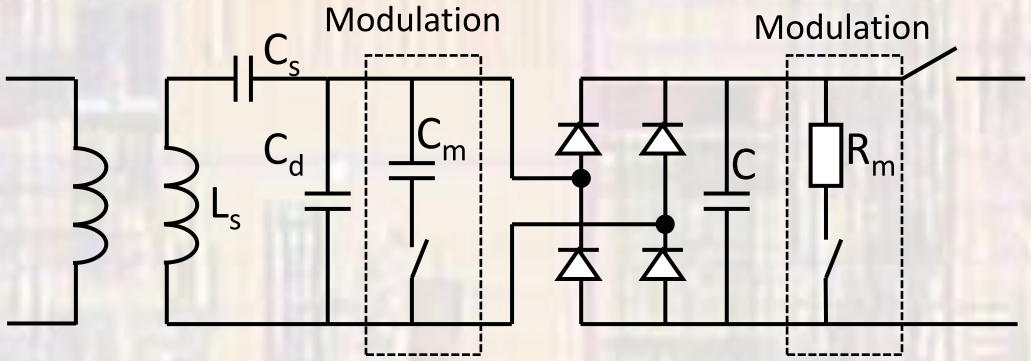




$$R_{P-eff} = \frac{V_S \frac{N_P}{N_S}}{I_S \frac{N_S}{N_P}} = \mathrm{R}\left(\frac{N_P}{N_S}\right)^2$$

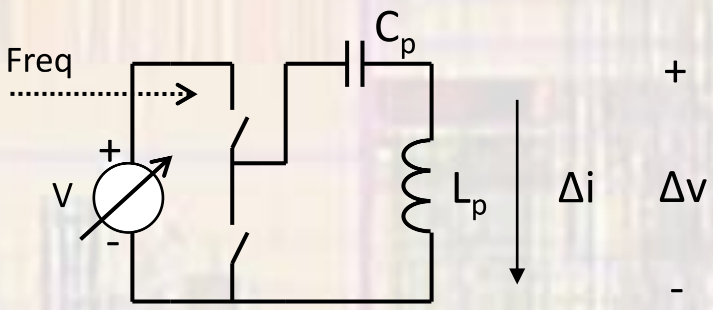
Wireless Charging

- Communications - Receiver
  - Qi standard (one of many)
  - Modulate the load
    - Switch either
      - Load resistor
      - Resonant capacitor
  - Load gets reflected back to the transmitter through the inductive interface



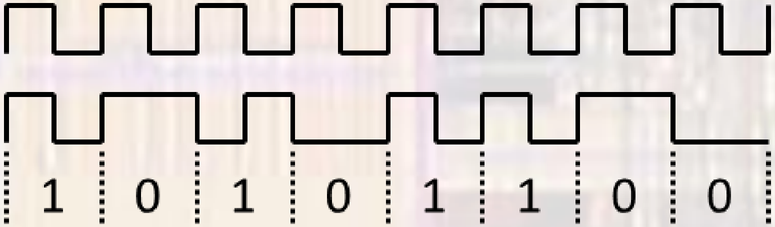
Wireless Charging

- Communications - Transmitter
  - Qi standard (one of many)
  - Reflected load results in changes to I and V
  - Sense the change to demodulate the communications signal

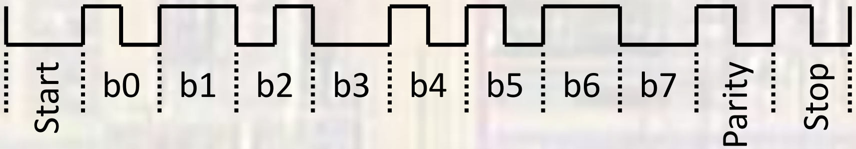


Wireless Charging

- Communications – Data Format
  - 2Kb/s
  - Bi-phase encoding
    - Data is in transition or no-transition
    - Every rising edge clock has a transition
    - Check falling edges (or run 2x clk rate) for transition or not
    - No system clock – uses clock recovery



  - Byte encoding
    - 1 start, 8b - lsb first, 1 parity, 1 stop



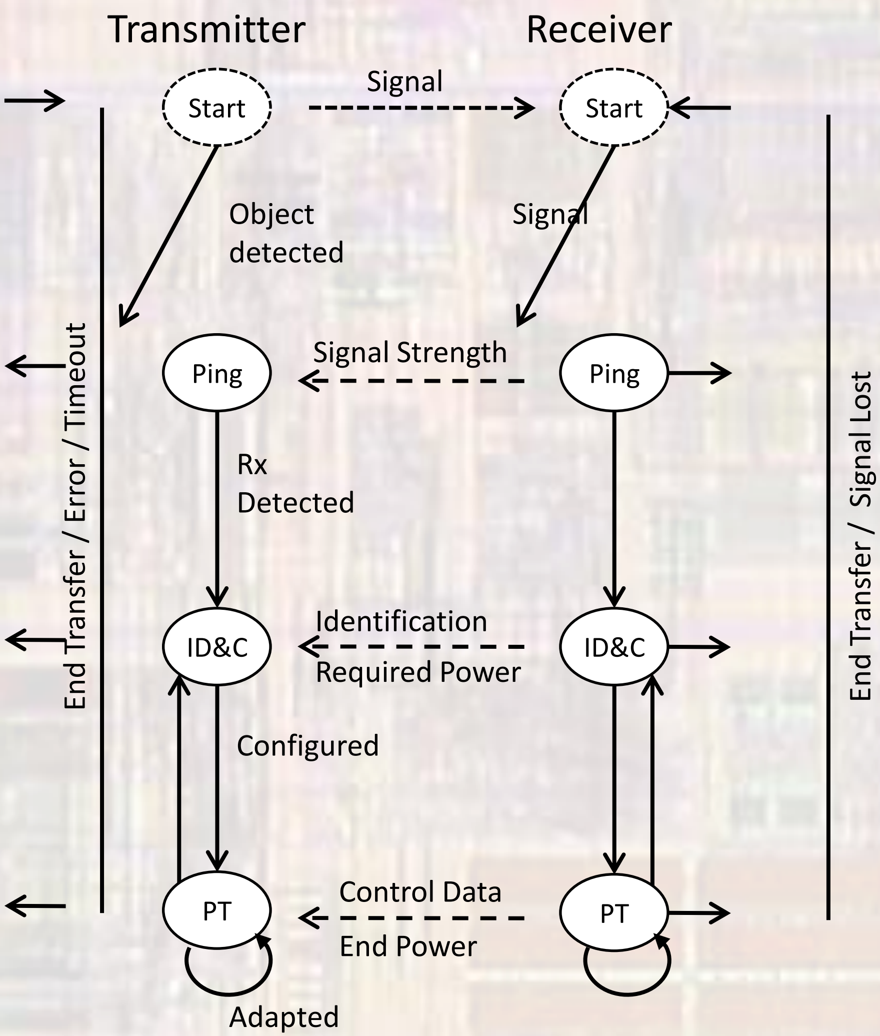
Wireless Charging

- Communications – Packet Structure
  - Preamble >= 11bit
  - Header - 1 Byte
    - Indicates packet type and message length
  - Message - 1 to 27 Bytes
    - One complete message per packet
  - Checksum (1 Byte)

Preamble	Header	Message	Checksum

Wireless Charging

- Communications – Process
  - Start
    - Transmitter provides signal and senses for presence of an object (potential receiver)
    - Receiver waits for signal
  - Ping
    - Receiver indicates presence by communicating received signal strength
    - Transmitter detects response of receiver
  - Identification & Configuration
    - Receiver communicates its identifier and required power
    - Transmitter configures for power transfer
  - Power Transfer
    - Receiver communicates control data
    - Transmitter adapts power transfer



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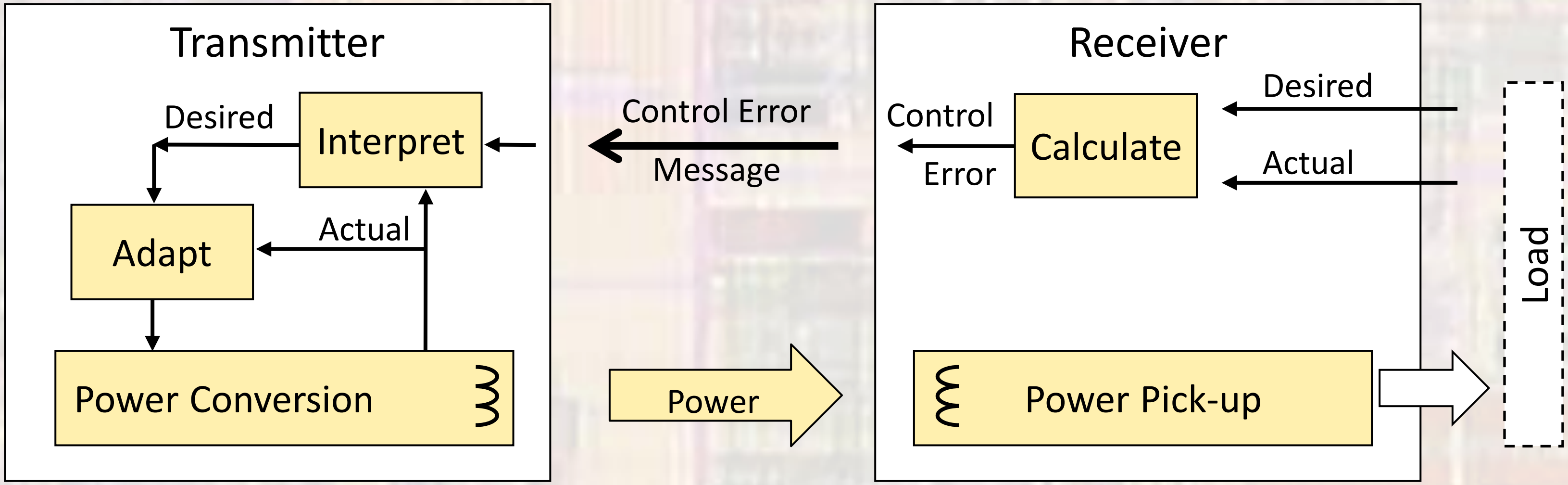
Wireless Charging

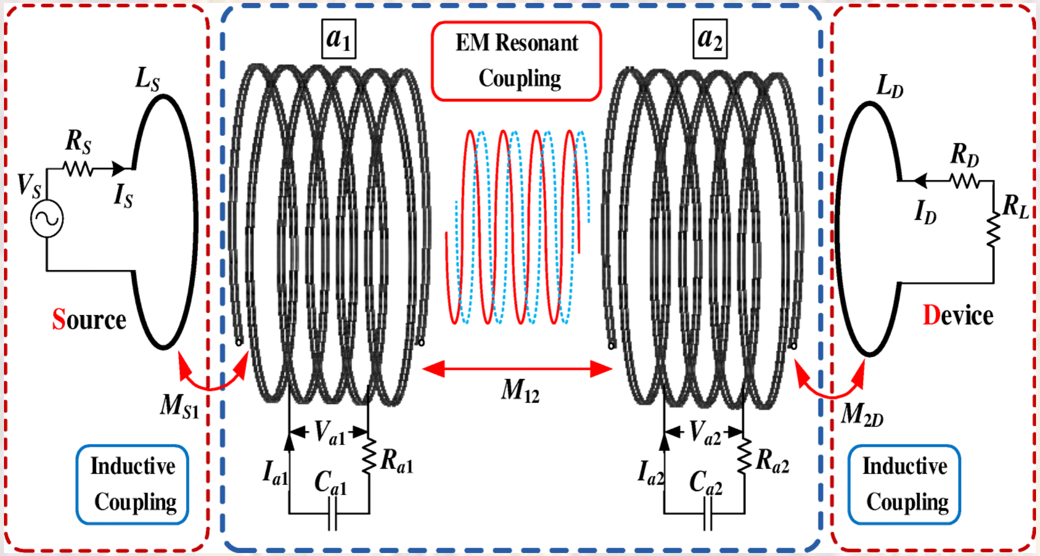
- Communications – Process
  - Receiver
    - Compares desired operating point to measured operating point
  - Transmitter
    - Modifies operating point to reduce communicated error to zero



src: WPC

Wireless Charging

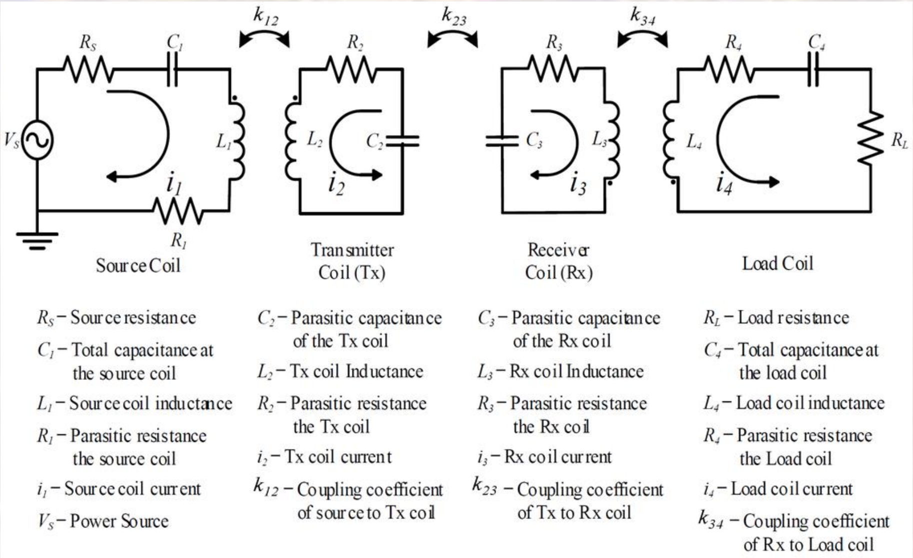
- Resonant Coupling
  - Idea originally attributed to Nikola Tesla
  - Developed at MIT
  - Use "tuned" coil on the receive side (or both sides)
    - Resonates at the transmit frequency
    - Lower transmit field strength required to excite the receiver
      - → more distance



EURASIP Journal on Wireless Communications and Networking, Zhang, X.

Wireless Charging

- Resonant Coupling
  - Model
    - Power transfer is a function of coil parameters and distance



$$k_{23} \cong \frac{\mu_0 \pi n^2 r^4}{2 L d_{23}^3}$$

n - # turns
r – radius
L – self inductance
d_{23} - distance

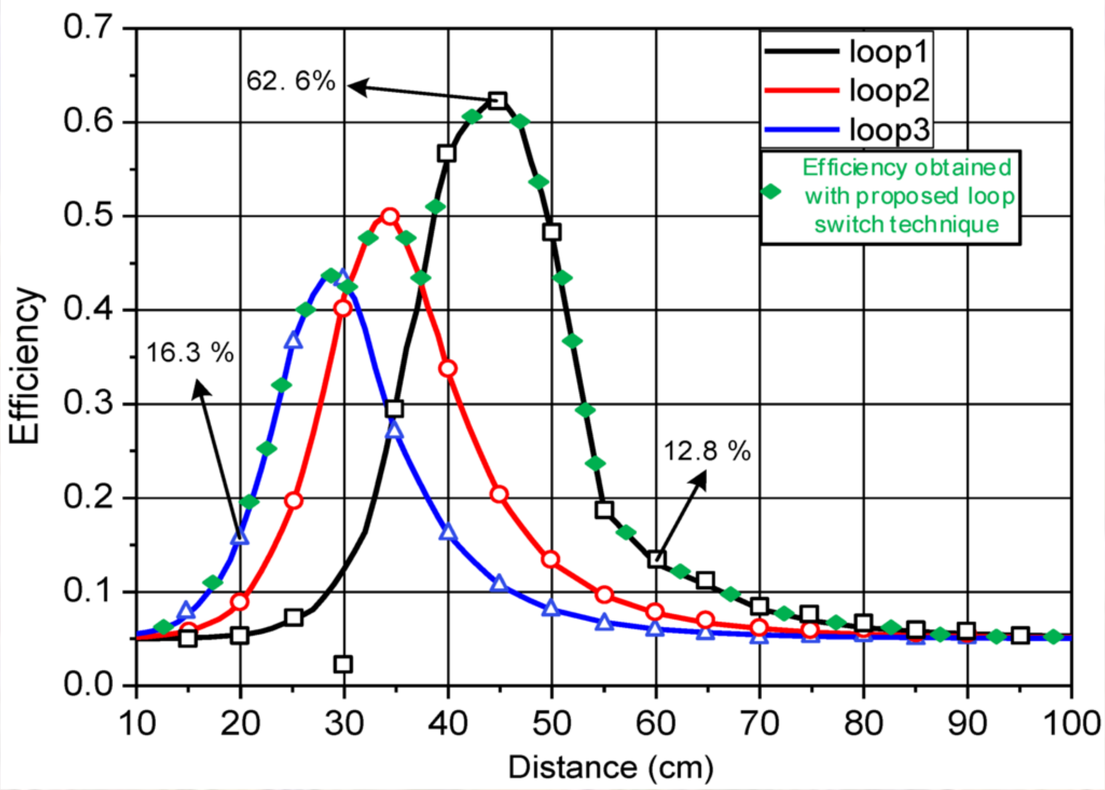
$$|S_{21opt}| = \frac{2k_{12opt}^2 k_{23} Q_1 Q_2^2}{\left(1 + k_{12opt}^2 Q_1 Q_2\right)^2 + k_{23}^2 Q_2^2}$$

$Q_1 = Q_4$
$Q_2 = Q_3$
$k_{12} = k_{34}$

Vijith Vijayakumaran Nair

Wireless Charging

- Resonant Coupling



Vijith Vijayakumaran Nair

Wireless Charging

- Comparison

Wireless Charging Technology

YONSEI UNIVERSITY

❖ Inductive vs. Resonant

Type		Inductive	Resonant
Frequency	Power transmission (Charging)	100~250 kHz (WPC) 232~278 kHz, 205~300 kHz (PMA)	6.78 MHz ± 15 kHz (A4WP)
	Power control (Communication)	In-band (Packet)	Out-band (BLE 2.4 GHz)
Standardization		WPC, AirFuel (PMA)	AirFuel (A4WP)
Characteristics		Compliant with Qi & PMA	Compliant with Rezence Multi device charging Free positioning

Wireless Charging

- Future

Wireless Charging

- Future