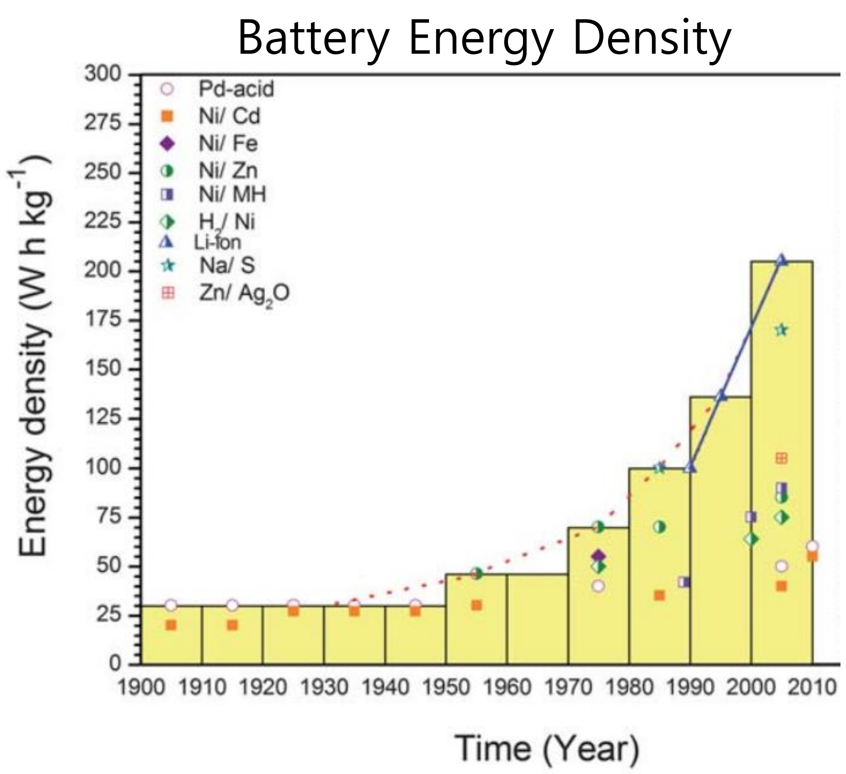
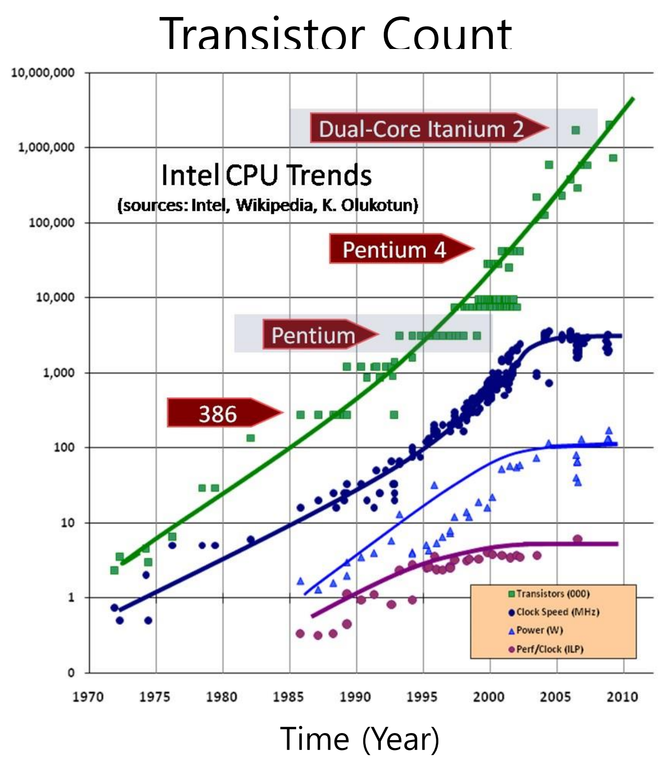
E-Space

Jonathan Scharf, Spencer Pietryka, Steve Bevacqua

Statement of Problem

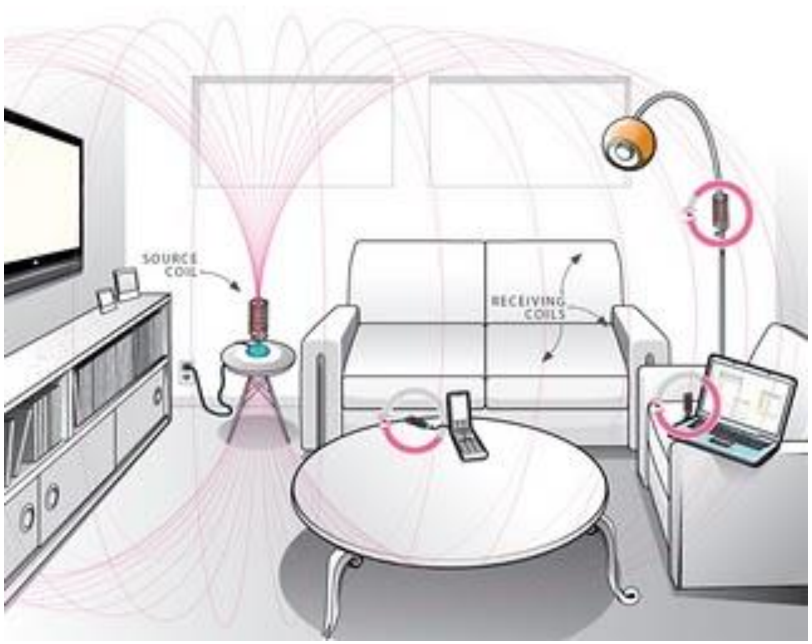
- Electronic devices more portable than ever
- Electronics technology outpaces battery technology
- Need to charge often or use many batteries

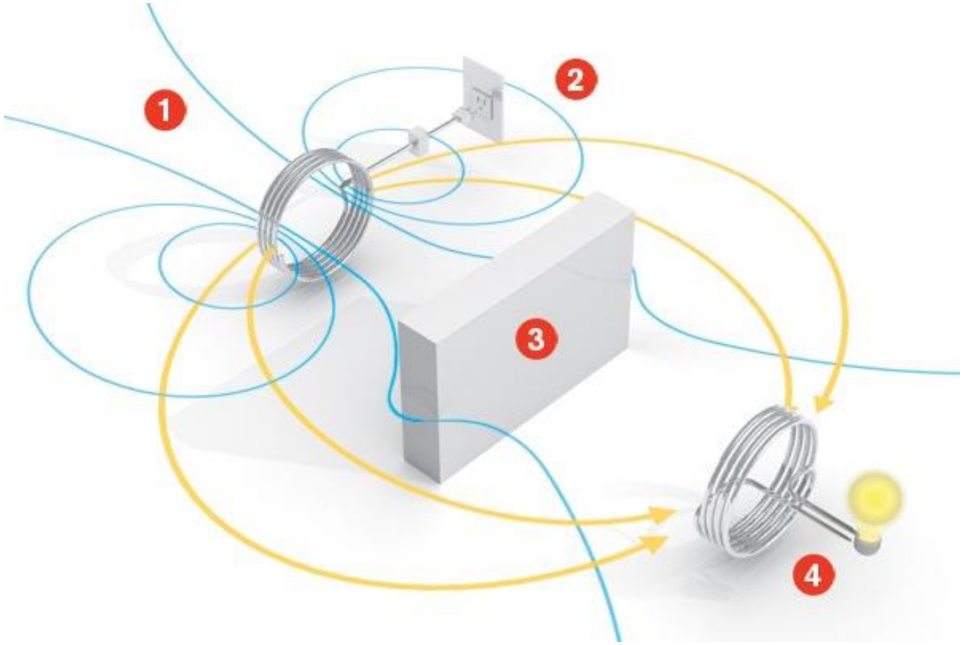




Proposed Solution

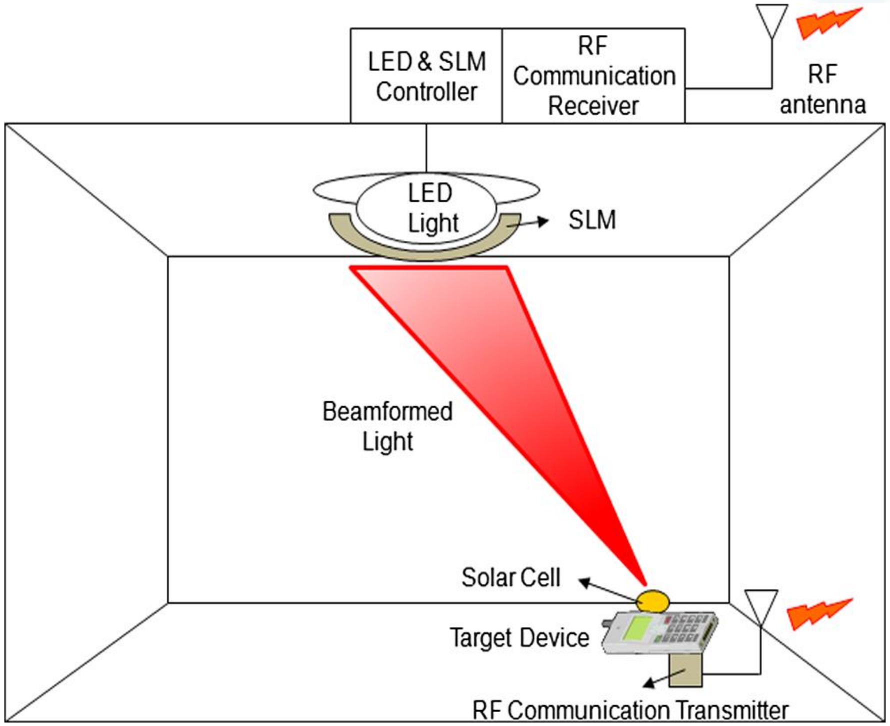
- Wireless transfer of power to charge devices or directly power devices
- Magnetic resonance charging can power multiple devices at once with high efficiencies
- Eliminate reliance on failure prone cables and connectors





Alternative Designs

- Inductive Coupling
  - Commercially available
  - Limited range (0-1cm)
  - Sensitive to position and orientation



- Power Beaming
  - Can transmit power farther distances
  - Requires direct line of sight
  - Hazardous

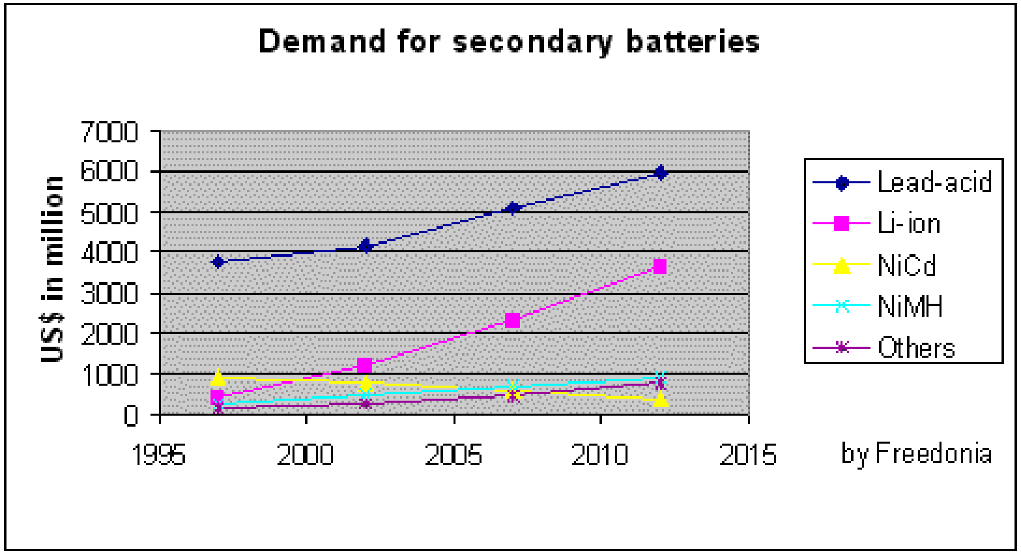
What Already Exists

- Rezence
  - Magnetic resonance wireless power standard
    -Operate at 6.78 MHz
    -Provide up to 50W over 5 cm
    -Power up to 8 devices
  - Board members include Intel, Samsung, WiTricity

- WiTricity
  - Developing technical specifications
  - Design and sell development kits for commercial use.
  - Demonstration kits: $1000

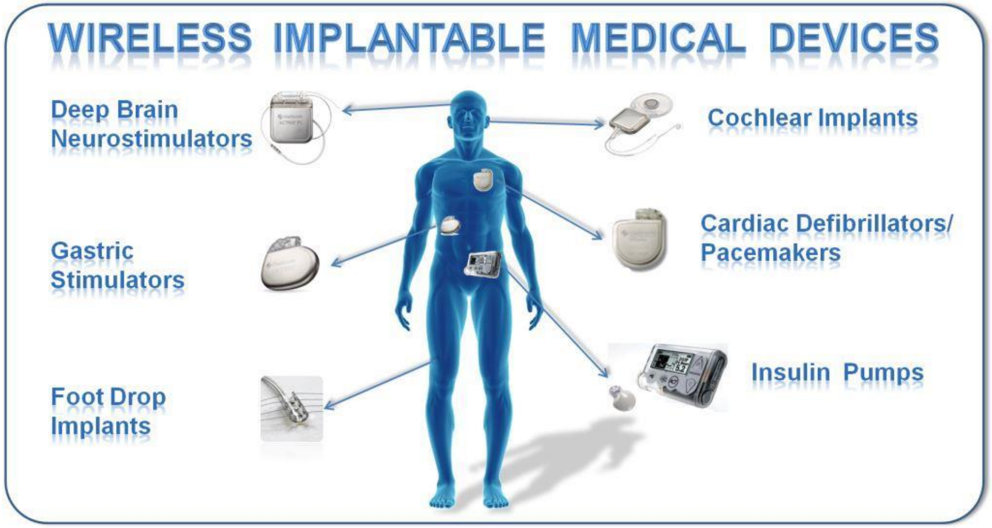
Societal Impacts

- Make devices more convenient – no need to plug in
- Make devices more reliable – eliminate cords and connectors
- Make devices safer – no sparking hazard, no open ports for wired connections
- Make devices more environmentally friendly – reduce need for electro-chemical batteries



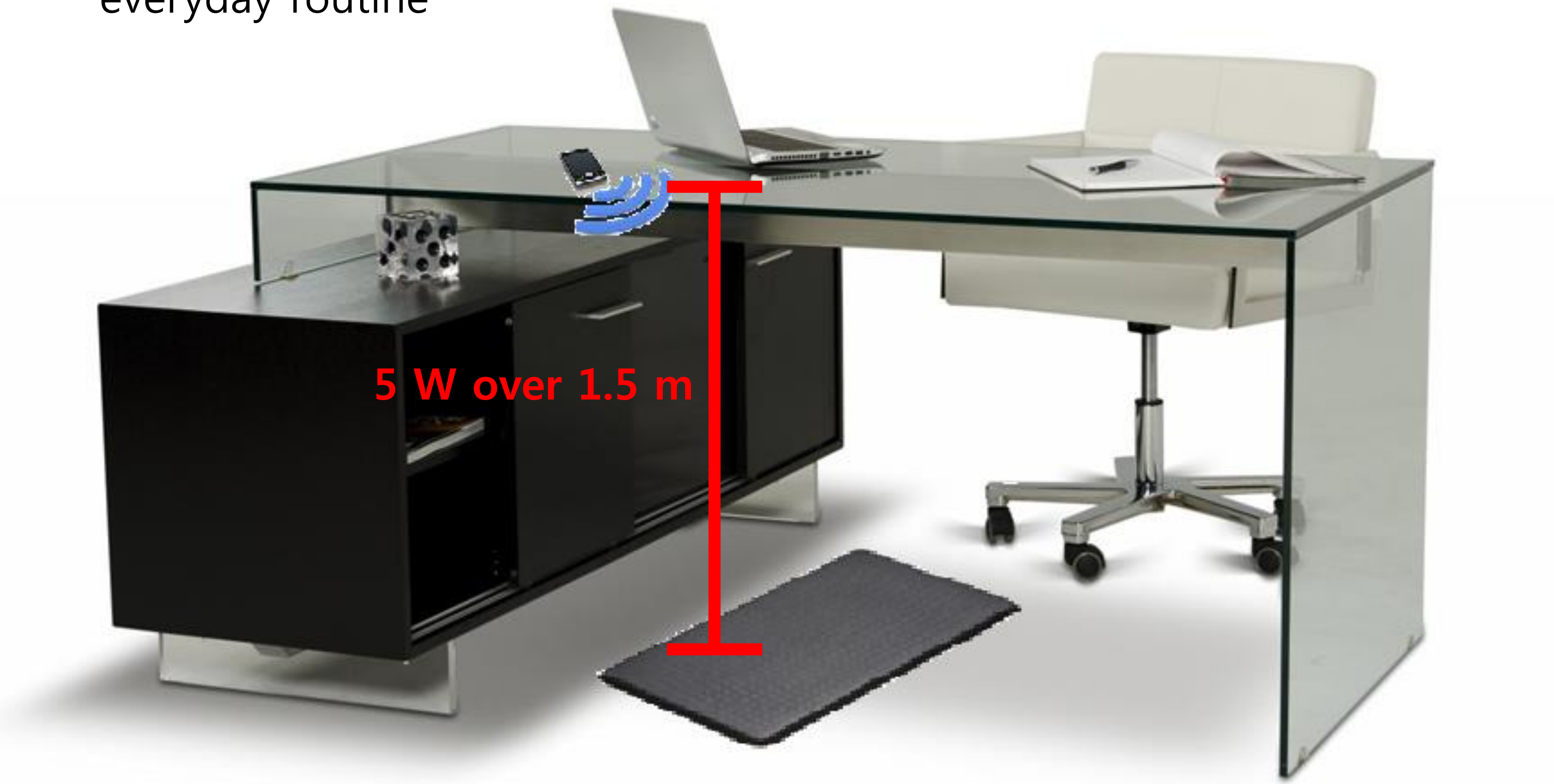
Applications

- Consumer Electronics
- Medical Implants
- Transportation
- Industrial Machinery



Our Application

- Our goal is to design a product that will make it easy for people to charge their phones without ever thinking about wires in their everyday routine
- Construct a charging pad and receiving phone case to allow for resonance wireless charging in a typical home or office



Possible Problems

- Lack of communication between devices – can “steal” power
- Safety concerns over human exposure to EM waves
- Attaining a high enough efficiency to charge or power devices

Factors to Consider

- Efficiency
  - Needs to be efficient in order to achieve the goal of charging a phone
- Health Concerns
  - Need to meet certain standards to ensure human safety
- Power Output
  - Needs to output enough power from the inductive coils in order to achieve our goal

Efficiency and Power

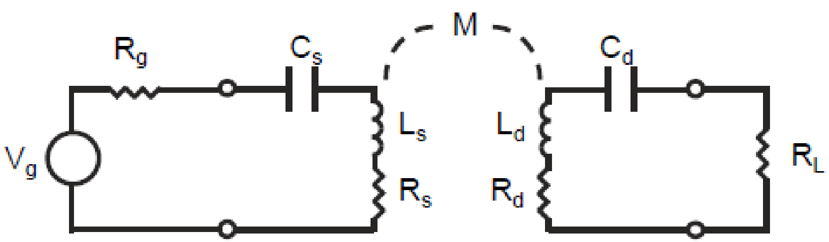


Figure 11: Equivalent circuit for the coupled resonator system.

$$\omega_0 = \frac{1}{\sqrt{LC}} \qquad M = k\sqrt{L_s L_d}$$

$$Q = \frac{\omega_0}{2\Gamma} = \sqrt{\frac{L}{C}}\frac{1}{R} = \frac{\omega_0 L}{R}$$

$$U = \frac{\omega M}{\sqrt{R_s R_d}} = \frac{\kappa}{\sqrt{\Gamma_s \Gamma_d}} = k\sqrt{Q_s Q_d}$$

$$\frac{P_L}{P_{g,max}} = \frac{4 \cdot U^2 \frac{R_g}{R_s}\frac{R_L}{R_d}}{\left((1+\frac{R_g}{R_s})(1+\frac{R_L}{R_d}) + U^2\right)^2}$$

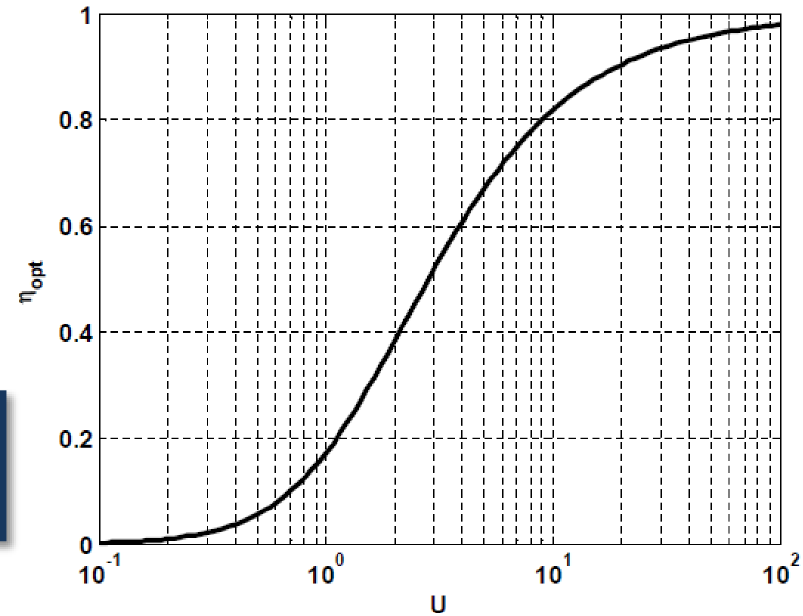
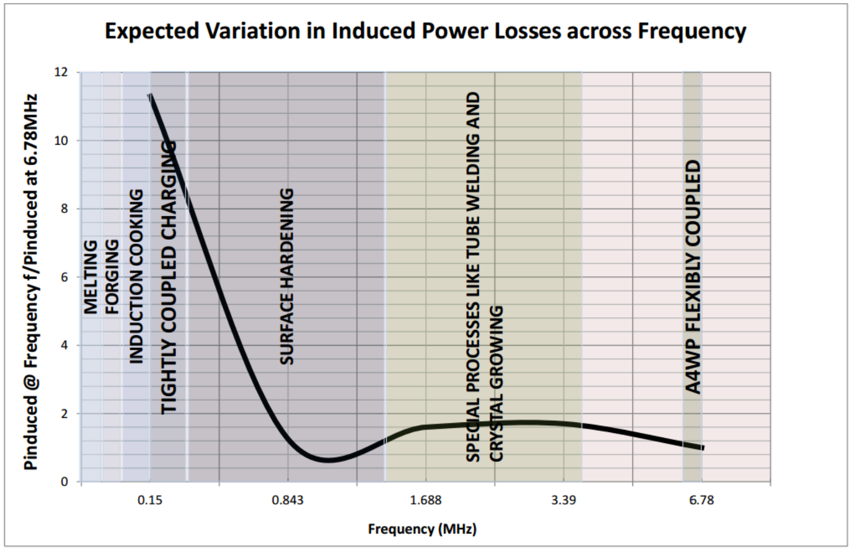


Figure 12: Optimum efficiency of energy transfer as a function of the figure-of-merit, U.

$$\eta_{opt} = \frac{U^2}{\left(1+\sqrt{1+U^2}\right)^2}$$

Frequency Selection

- Tightly-coupled (Inductive Charging) and low frequency approaches **may cause heating in excess of 50ºC of nearby metallic objects.**
- "Laboratory measurements**… reveal differences in the range 2-20 [times] greater power loss** (induced heating) **in the 100s kHz range relative to those at 6.78MHz"**
- **ISM Band** in the figure reveals the frequencies that are **globally accessible and unrestricted**



Tseng, R.; von Novak, B.; Shevde, S.; Grajski, K.A., "Introduction to the alliance for wireless power loosely-coupled wireless power transfer system specification version 1.0," in Wireless Power Transfer (WPT), 2013 IEEE , vol., no., pp.79-83, 15-16 May 2013

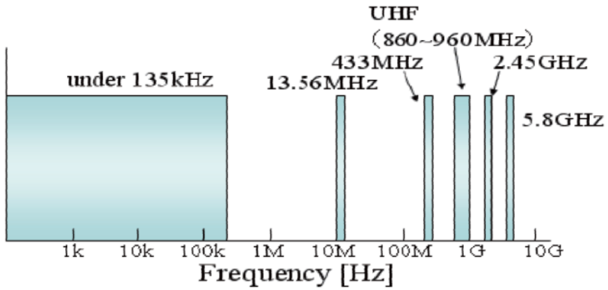


Figure 2.4 ISM Band

Health Concerns

- The IEEE and ICNIRP recommend a localized general public SAR limit of **4 W/kg for limbs and 2 W/kg for the head and trunk in 10 g of tissue.**

	SAR [W/kg] (Whole Body Average)	**SAR [W/kg]** (Head/Trunk)	**SAR [W/kg]** (Limbs)	**Induced E** [V/m] (All Tissue)	**Induced J** [mA/m2] (Central Nervous System)
FCC	0.08	1.6 (1 g)	4 (10 g)	--	--
ICNIRP 2010	0.08	2.0 (10 g)	4 (10 g)	$1.35 \times 10^{-4} f$ (f in Hz)	--
ICNIRP 1998	0.08	2.0 (10 g)	4 (10 g)	--	$f/500$ (f in Hz)

Tissue Heating

- **ICNIRP recommends an internal E-field limit of 1.35 x 10^{-4} x f V/m.**

- **The IEEE recommends internal E-field limits that range from 2.1 x 10^{-4} x f V/m to 6.3 x 10^{-4} x f V/m** depending on which part of the body is exposed.

RADIO FREQUENCY ELECTROMAGNETIC FIELDS, 3 kHz TO 300 GHz — IEEE Std C95.1, 1999 Edition

Table 2—Maximum permissible exposure for uncontrolled environments*

Part A: Electromagnetic Fields†					
Frequency range (MHz) 1	**Electric field strength (E) (V/m)** 2	**Magnetic field strength (*H*) (A/m)** 3	**Power density (*S*) E-field, H-field (mW/cm^2)** 4	**Averaging time $\|E\|^2$, *S*** or **(min)** 5	**$\|H\|^2$**
0.003–0.1	614	163	(100, 1 000 000)‡	6	6
0.1–1.34	614	$16.3/f$	$(100, 10\,000/f^2)$‡	6	6
1.34–3.0	$823.8/f$	$16.3/f$	$(180/f^2, 10\,000/f^2)$	$f^2/0.3$	6
3.0–30	$823.8/f$	$16.3/f$	$(180/f^2, 10\,000/f^2)$	30	6
30–100	27.5	$158.3/f^{1.668}$	$(0.2, 940\,000/f^{3.336})$	30	$0.0636\,f^{1.337}$
100–300	27.5	0.0729	0.2	30	30
300–3000	—	—	$f/1500$	30	
3000–15 000	—	—	$f/1500$	$90\,000/f$	
15 000–300 000			10	$616\,000/f^{1.2}$	
NOTE—*f* is the frequency in MHz.					

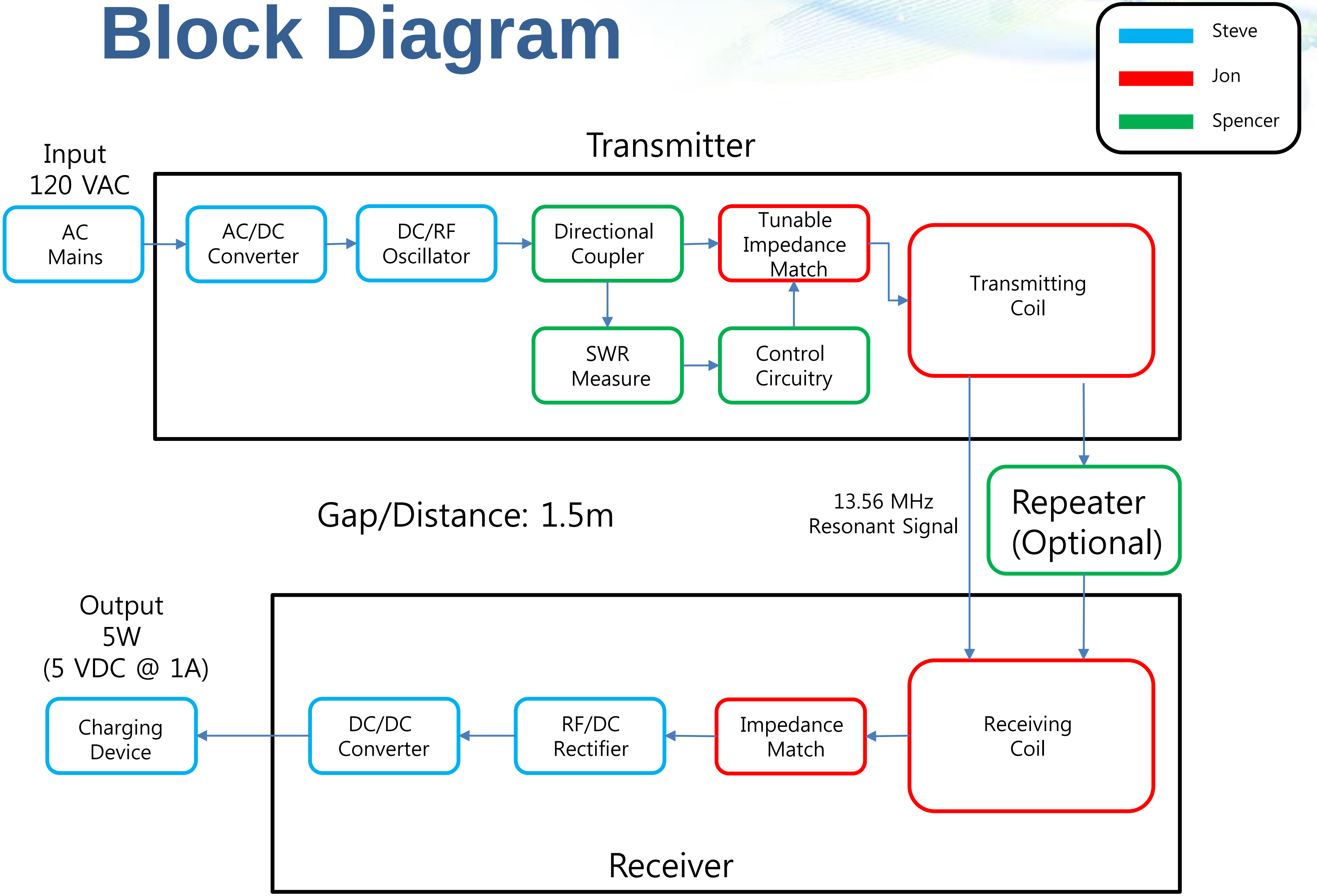
*See Figure E.1 and Figure E.4 for graphical depictions of MPEs.
†The exposure values in terms of electric and magnetic field strengths are the mean values obtained by spatially averaging the squares of the fields over an area equivalent to the vertical cross section of the human body (projected area).
‡These plane-wave equivalent power density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

Technical Requirements

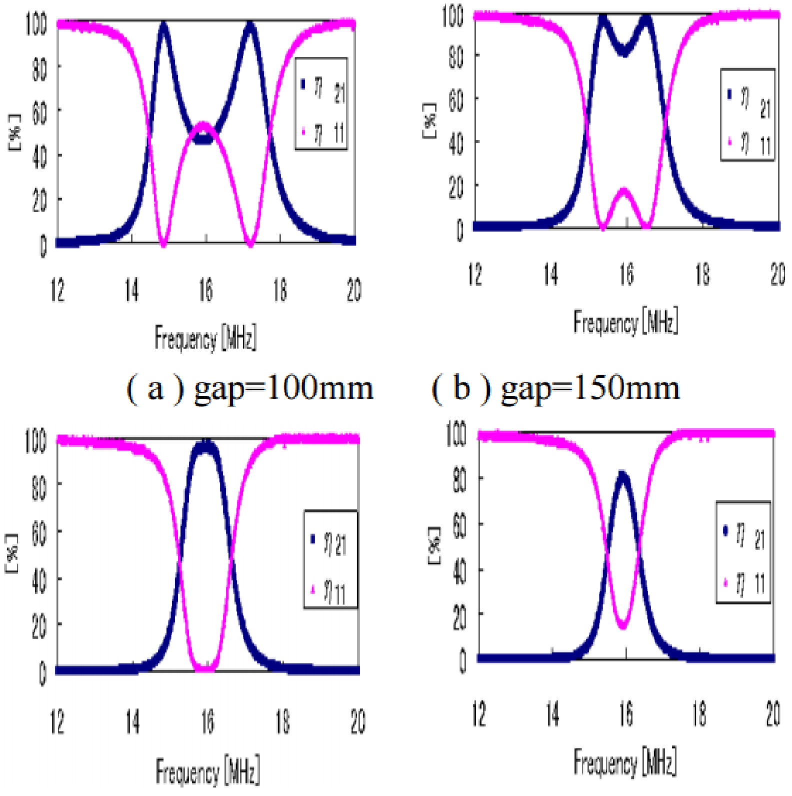
Input Specifications	120 VAC at 60Hz
Frequency	13.56 MHz
Distance/Range	1.5 m
Minimum Output Power	5W
Minimum Wireless Transfer Efficiency	≥70%
Minimum Total System Efficiency	≥50%
Maximum Electric Field	60.75 V/m
Maximum Magnetic Field	1.20 A/m

Maximum Receiver Size:

Block Diagram



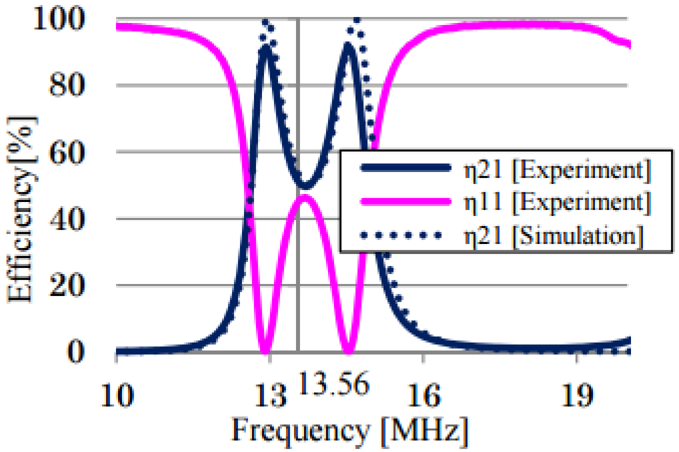
Tunable Impedance Matching



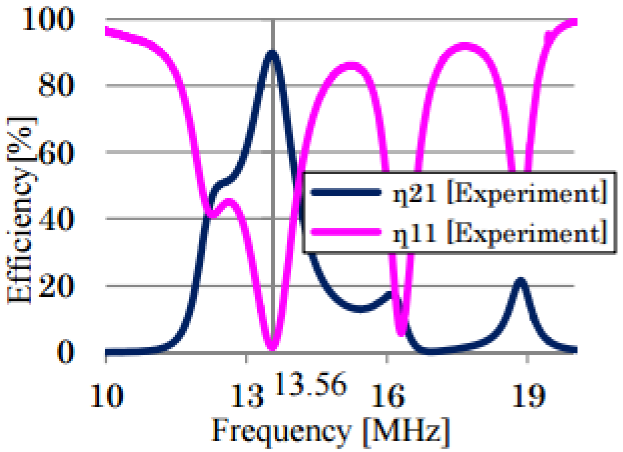
(a) gap=100mm (b) gap=150mm

(c) gap=200mm (d) gap=250mm

Figure 3: Efficiency vs frequency graph [2].



(a) Before matching

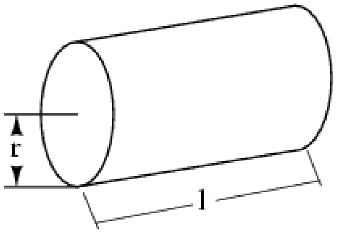


(b-2) After matching: Air core

Transmitter and Receiver

$$L = \frac{N^2 \mu A}{l}$$

$$\mu = \mu_r \mu_0$$



Where,

L = Inductance of coil in Henrys

N = Number of turns in wire coil (straight wire = 1)

μ = Permeability of core material (absolute, not relative)

μ_r = Relative permeability, dimensionless (μ_0=1 for air)

μ_0 = 1.26×10^{-6} T-m/At permeability of free space

A = Area of coil in square meters = πr^2

l = Average length of coil in meters

$$R = \frac{2\pi a N}{\sigma 2\pi r \delta} = \frac{aN}{\sigma r \delta}$$

with the following definitions of physical parameters:

a = major radius of coil

r = cross-sectional radius of wire

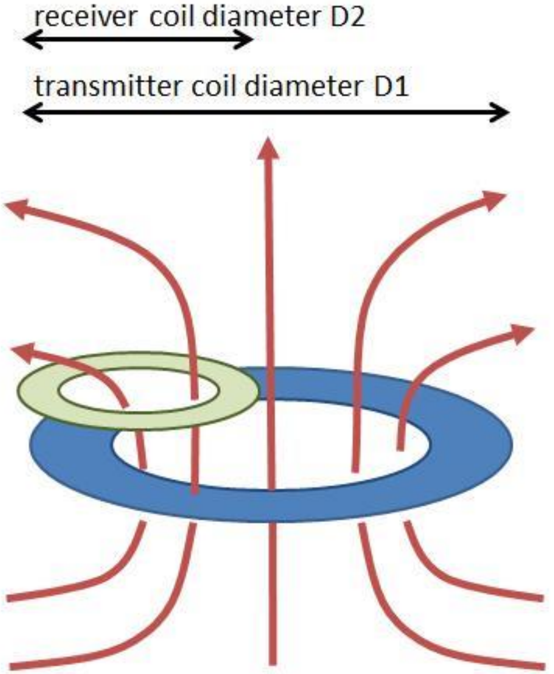
N = number of turns

σ = copper conductivity ($\sigma = 5.8 \times 10^7$ S/m)

f = source frequency (f = 13.56 MHz)

$$\delta = \frac{1}{\sqrt{\pi f \mu_0 \sigma}} \text{ (skin depth)}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$$

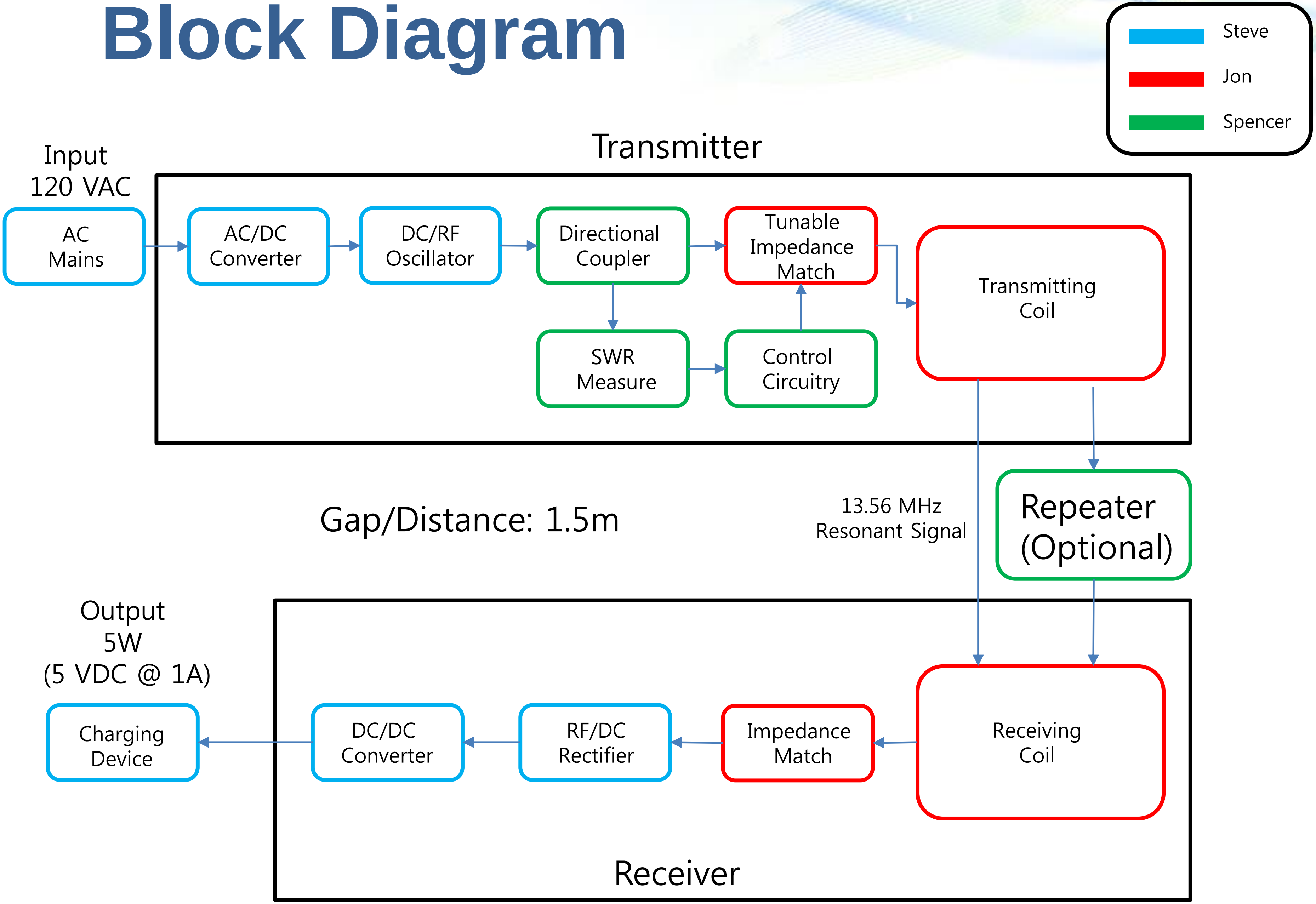


loosely coupled coils: D2 much smaller than D1

$$Q = \frac{\omega_0}{2\Gamma} = \sqrt{\frac{L}{C}}\frac{1}{R} = \frac{\omega_0 L}{R}$$

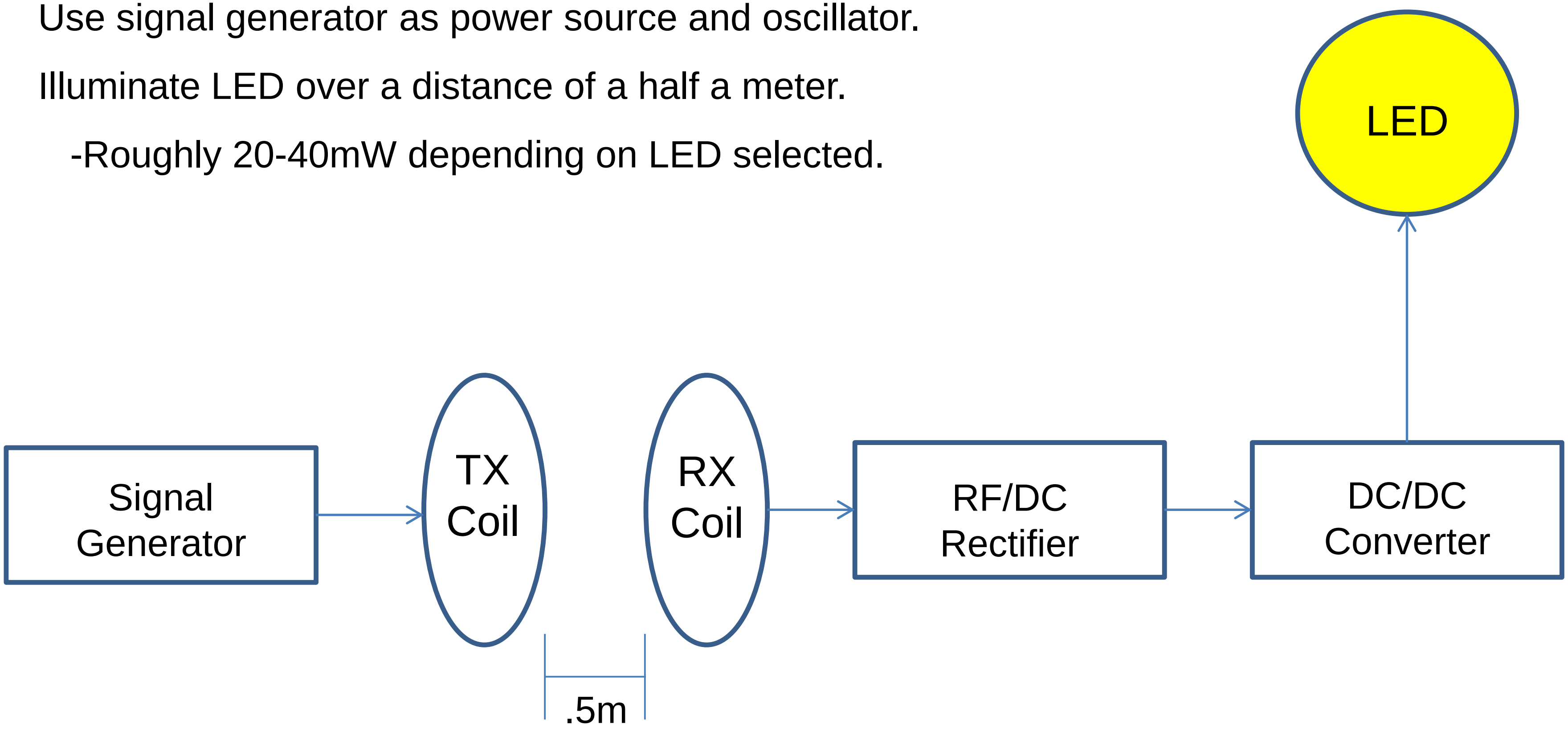
$$U = \frac{\omega M}{\sqrt{R_s R_d}} = \frac{\kappa}{\sqrt{\Gamma_s \Gamma_d}} = k\sqrt{Q_s Q_d}$$

Block Diagram



MDR Deliverables

- Create transmitter and receiver coils.
- Use signal generator as power source and oscillator.
- Illuminate LED over a distance of a half a meter.
  -Roughly 20-40mW depending on LED selected.



Questions and Comments