WIRELESS POWER

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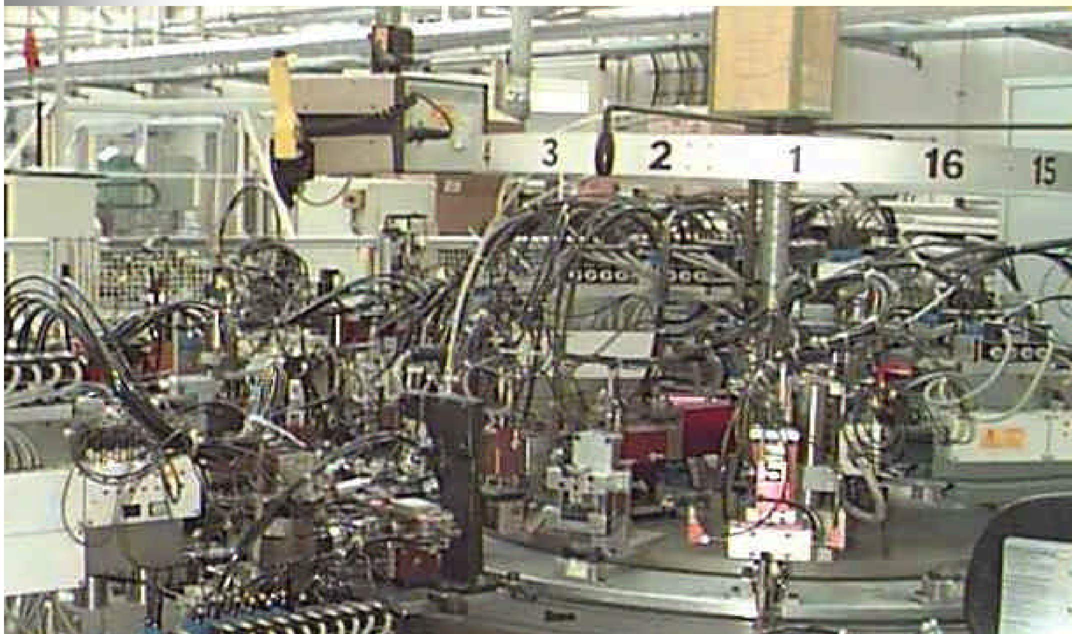
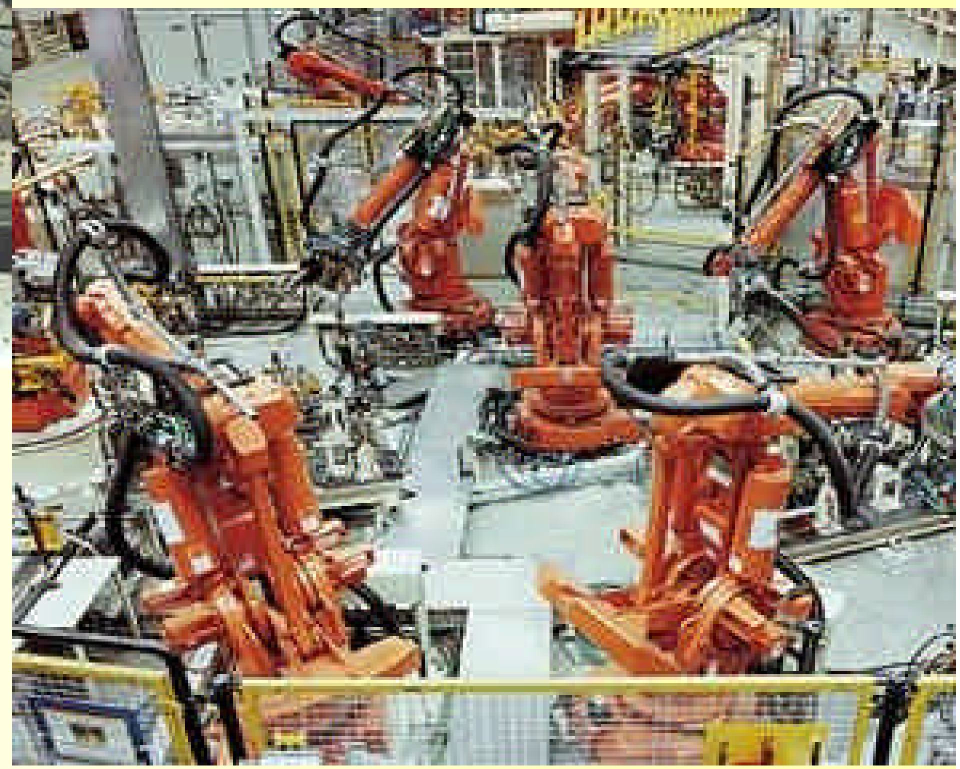
Overview

Wireless Power Technology Applications





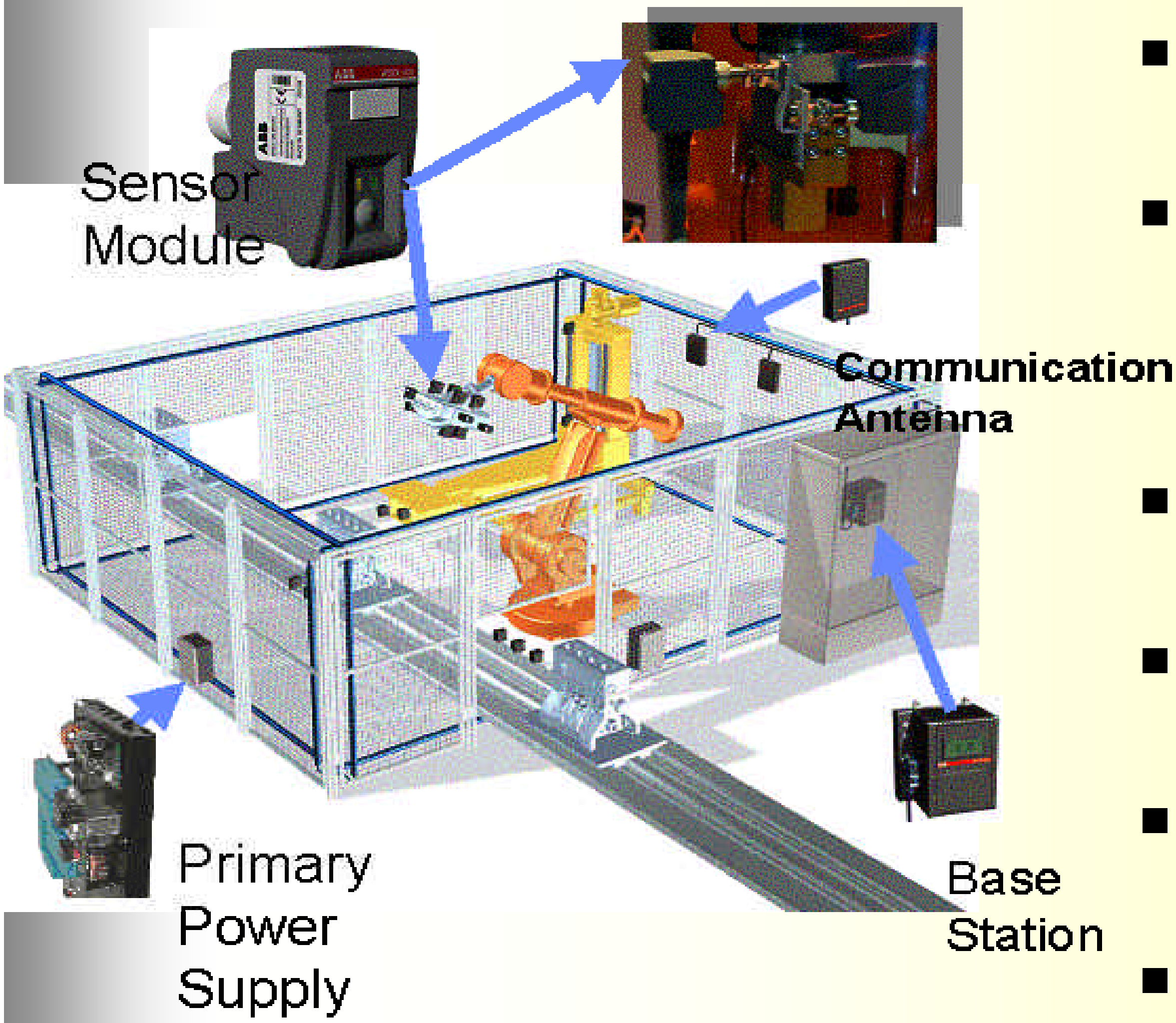
Assembly Machines

Smaller areas (> 2 m³)

Robot chains

Large areas (54 m³ - entire hall)

Wireless Power System



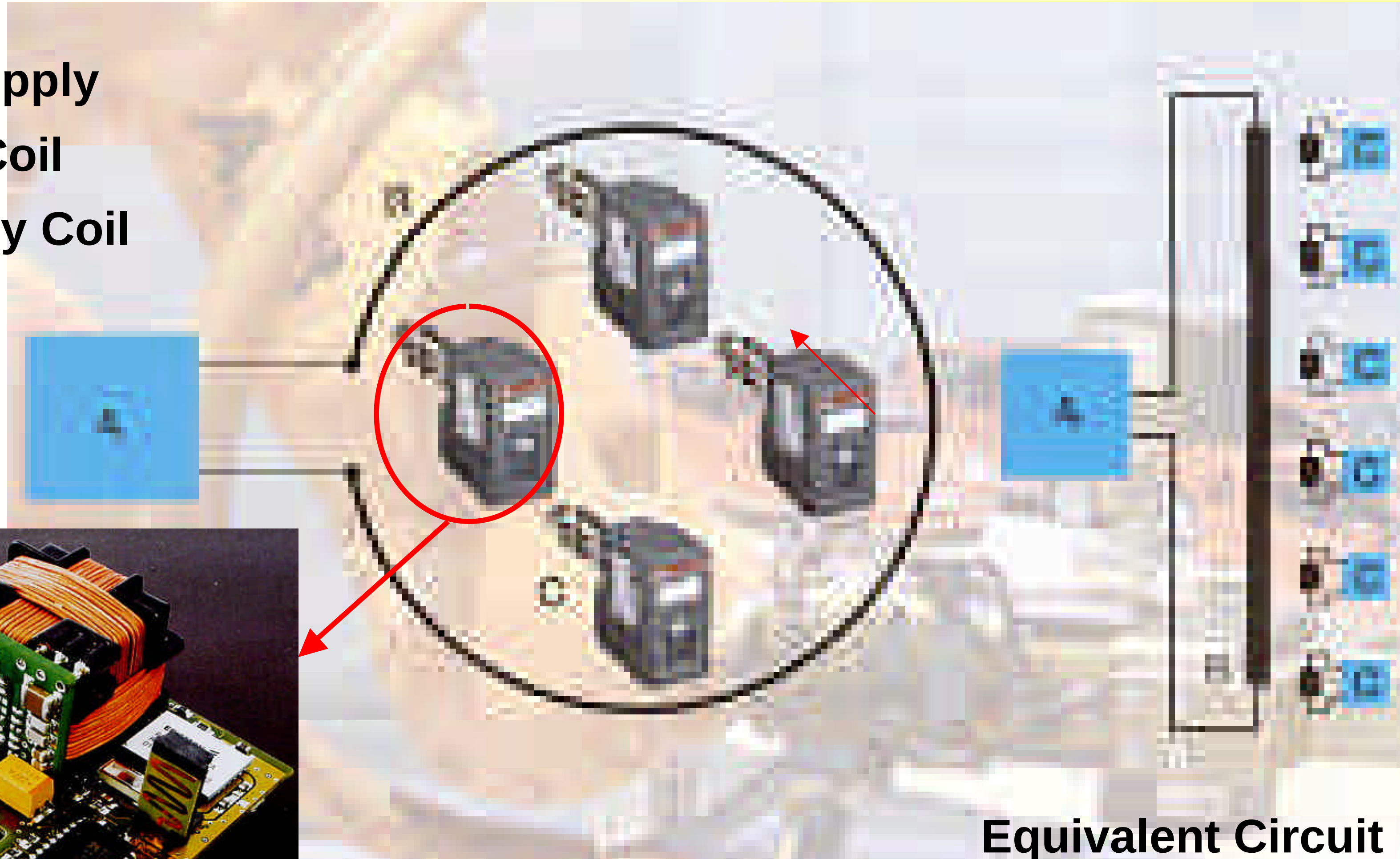
- Transformer with low coupling values of 0.01- 0.1%.
- Primary winding around the supplied volume. Secondary(s) are receiver coils with ferrite cores
- Coupling accomplished through field strength (H).
- Primary coils in a Helmholtz-like setup: Fairly uniform H
- Omni-directional receiver structure
- Rotating magnetic field

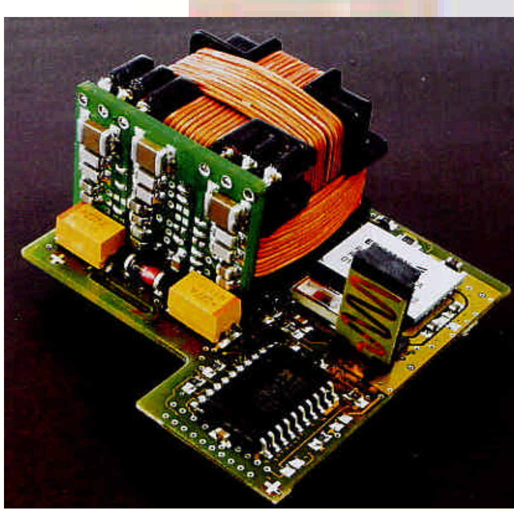
Wireless Power System (cont'd)

A. - Power Supply

B. - Primary Coil

C. - Secondary Coil



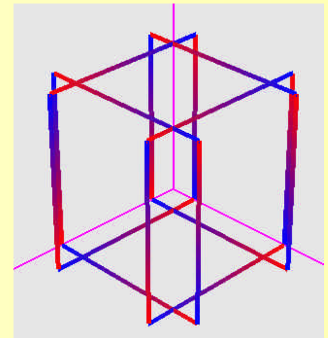


Equivalent Circuit (inductive coupling

Magnetic Field Characteristics

Rotating field

- Created by two primary coil sets that are 90° out of phase both spatially and electrically
- Maintains a constant magnitude over time and can provide constant power to the secondary coils

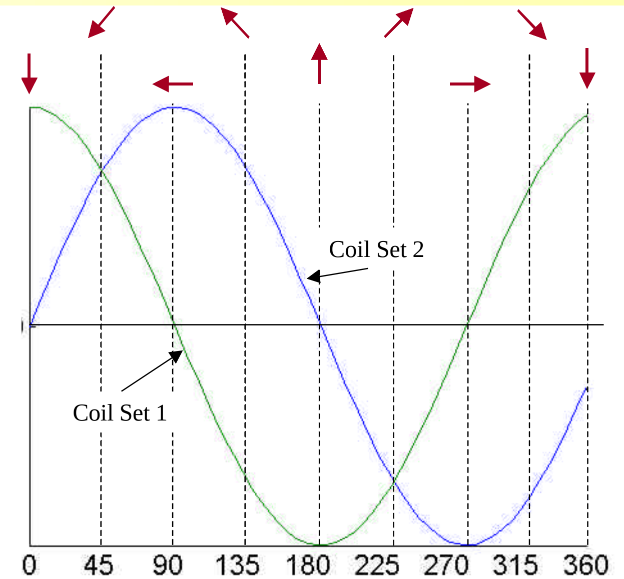


$$\vec{H} = \hat{a}_x k I_x \sin \omega t$$

$$\vec{H} = \hat{a}_y k I_y \cos \omega t$$

$$\text{with} \quad k = 4\sigma\left(-\sin\left(\frac{\pi}{4}\right)\frac{IL}{2\pi r\sqrt{L^2 + r^2}}\right)$$

$$|H| = \sqrt{H_x^2 + H_y^2} = \sqrt{(k + I_x)^2 + (k + I_y)^2}$$

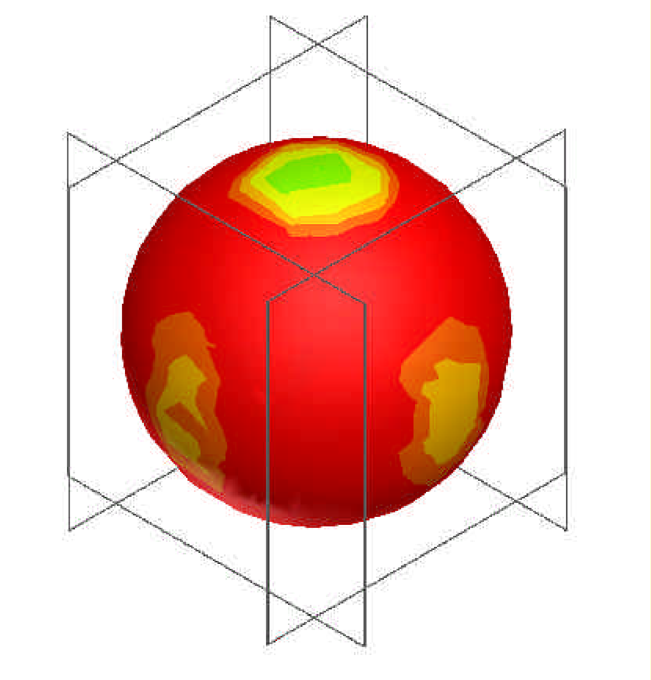


- Has the additional advantage of mitigating the problems of shielding

Primary Coil Design

Optimum distance between primary coils

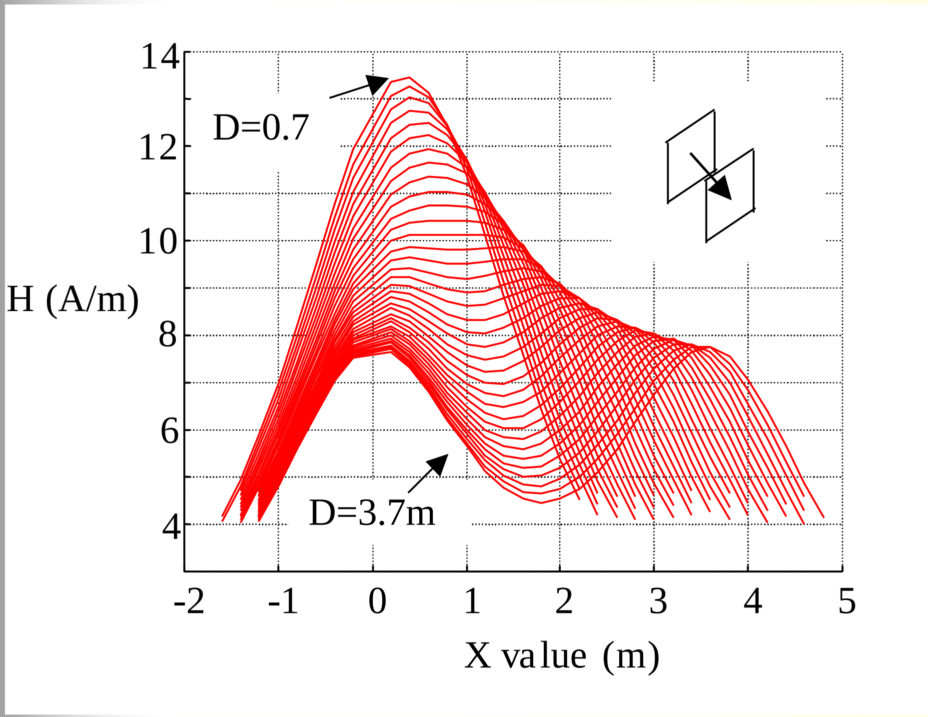
- Find Helmholtz distance (grad H = 0)
- Determine maximum allowable deviation from field value at the center of the system and vary the distance to achieve maximum volume of desired field strength
- Several methods exist to find the volume of specified field strength inside the operating volume
  1. Estimate volume as a cube
  2. Estimate volume as a sphere
  3. Summation of small "volume elements" (FEM)

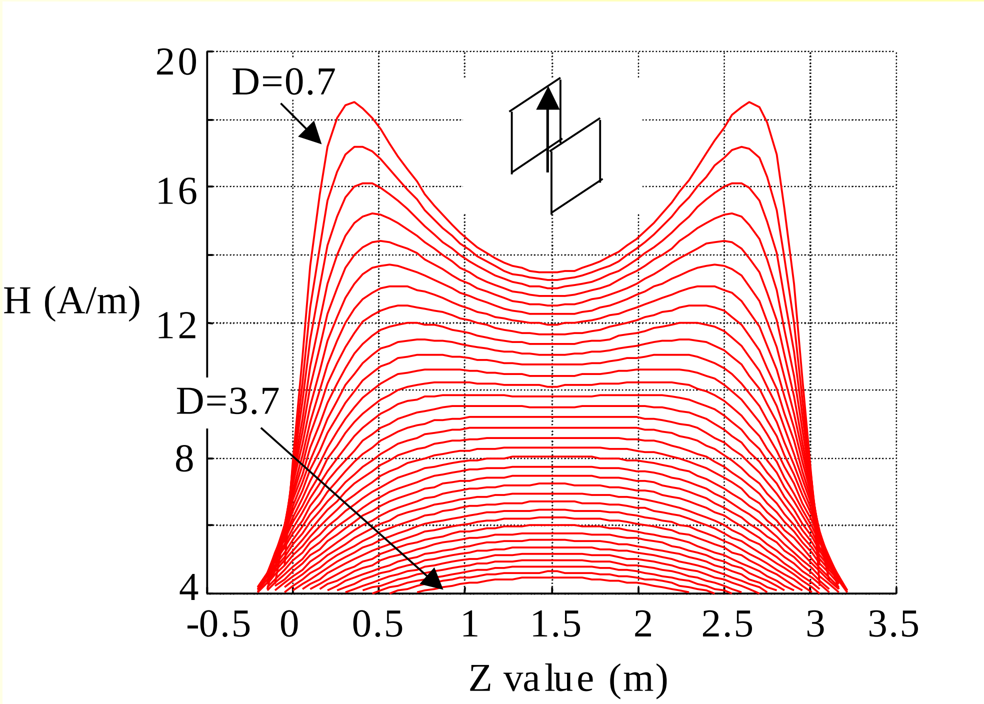


Optimization of Coil Separation Distance

Estimate volume as a cube

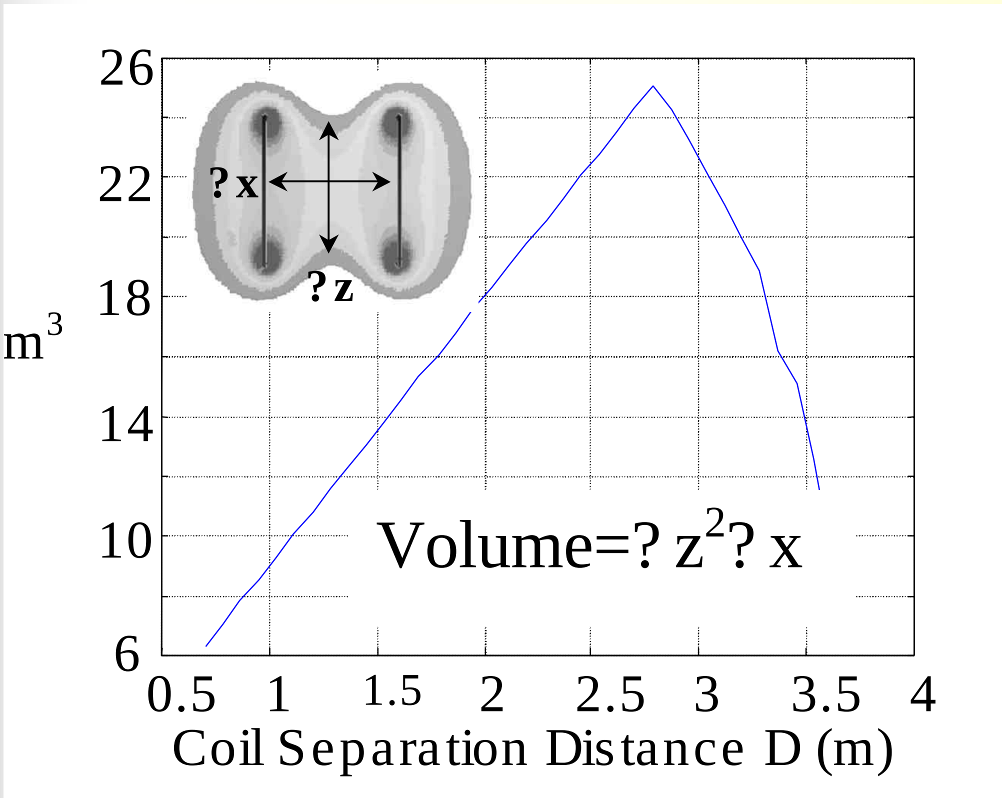
Volume of field strength at X A/m or greater can be estimated by assuming that the volume is cube-shaped

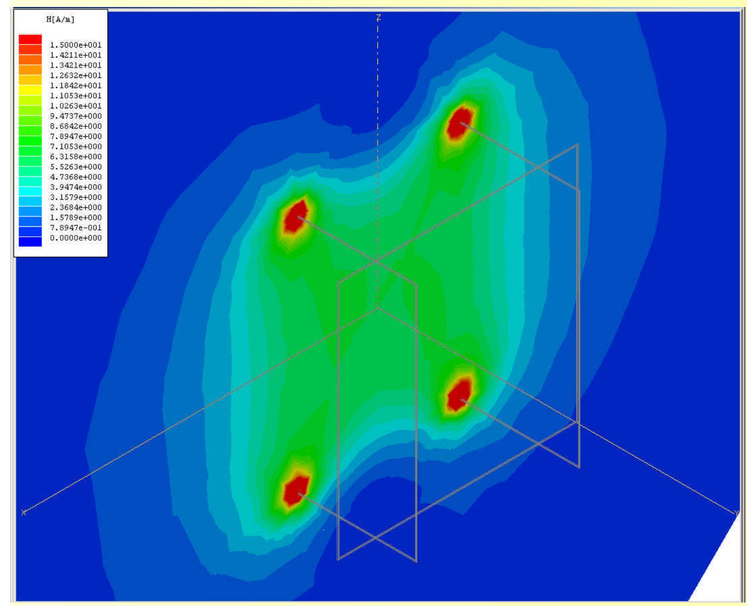




Optimization of Coil Separation Distance

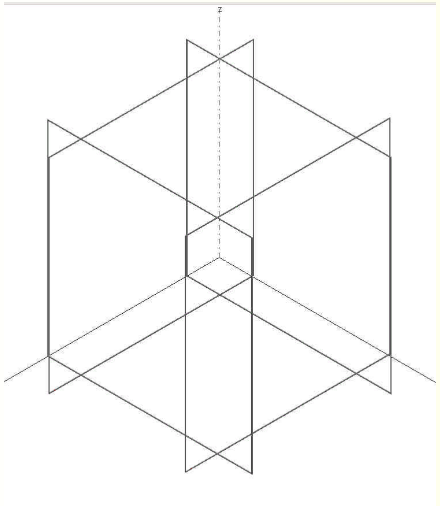
- The optimum distance between the primary coils in this example is 2.7 meters

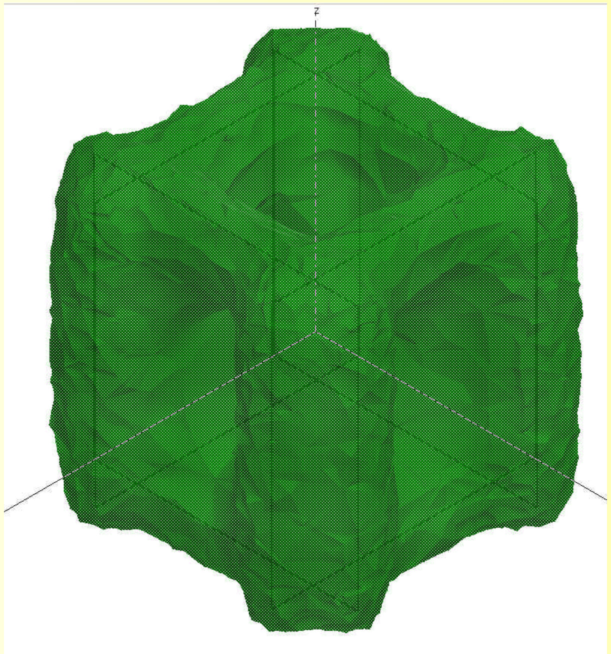




Optimization of Coil Separation Distance

Optimum distance of separation can also be found by maximizing the total volume occupied by a desired field strength

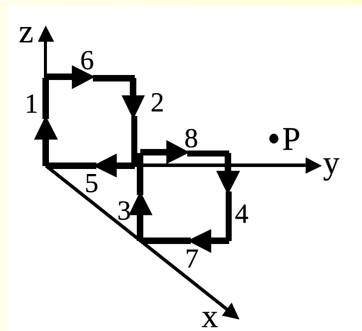


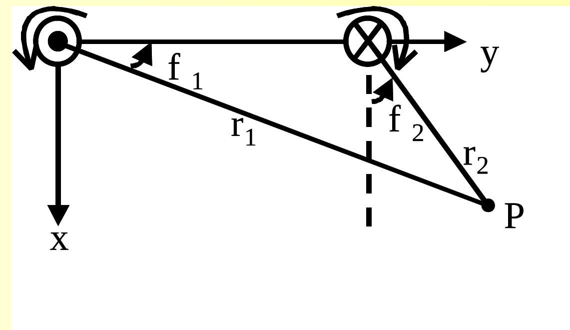


Field Calculation Methods

Field intensity (H) described in the near-field

- H can be expressed as the vector sum of the fields created when current passes through each of the straight elements comprising the coils





- For multiple coils

$$\overline{\varpi} \; H = \sum_{i=1}^{2s}\left[(-1)^{i}\sin f_i X_i \hat{a}_x + (-1)^{i+1}\cos f_i X_i \hat{a}_y\right] + \sum_{i=2s+1}^{4s}\left[(-1)^{i+1}\sin f_i X_i \hat{a}_z + (-1)^{i}\cos f_i X_i \hat{a}_x\right]$$

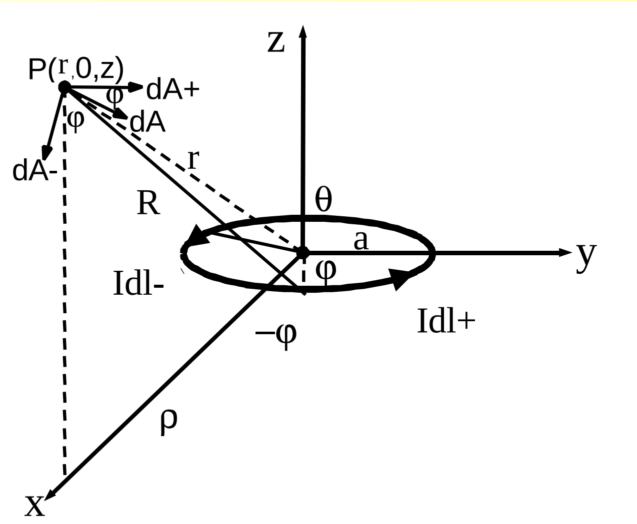
where $X_i = \dfrac{IL_i}{2pr_i\sqrt{L_i^{\,2} + r_i^{\,2}}}$

Field Calculation Methods (cont'd)

Field intensity described in the near field

- For a single coil

$$|H| = \frac{I}{2p\sqrt{(a+r)^2+z^2}}\left[\left[\frac{z^2}{r^2}\left[\frac{a^2+r^2+z^2}{(a-r)^2+z^2}E(k)-K(k)\right]\right]^2+\left[\frac{a^2-r^2-z^2}{(a-r)^2+z^2}E(k)+K(k)\right]^2\right]^{1/2}$$



where

$$K(k) = \int_0^{p/2} \frac{d\Phi}{\sqrt{1-k^2 \sin^2 \Phi}}$$

$$E(k) = \int_0^{p/2} \sqrt{1-k^2 \sin^2 \Phi}\, d\Phi$$

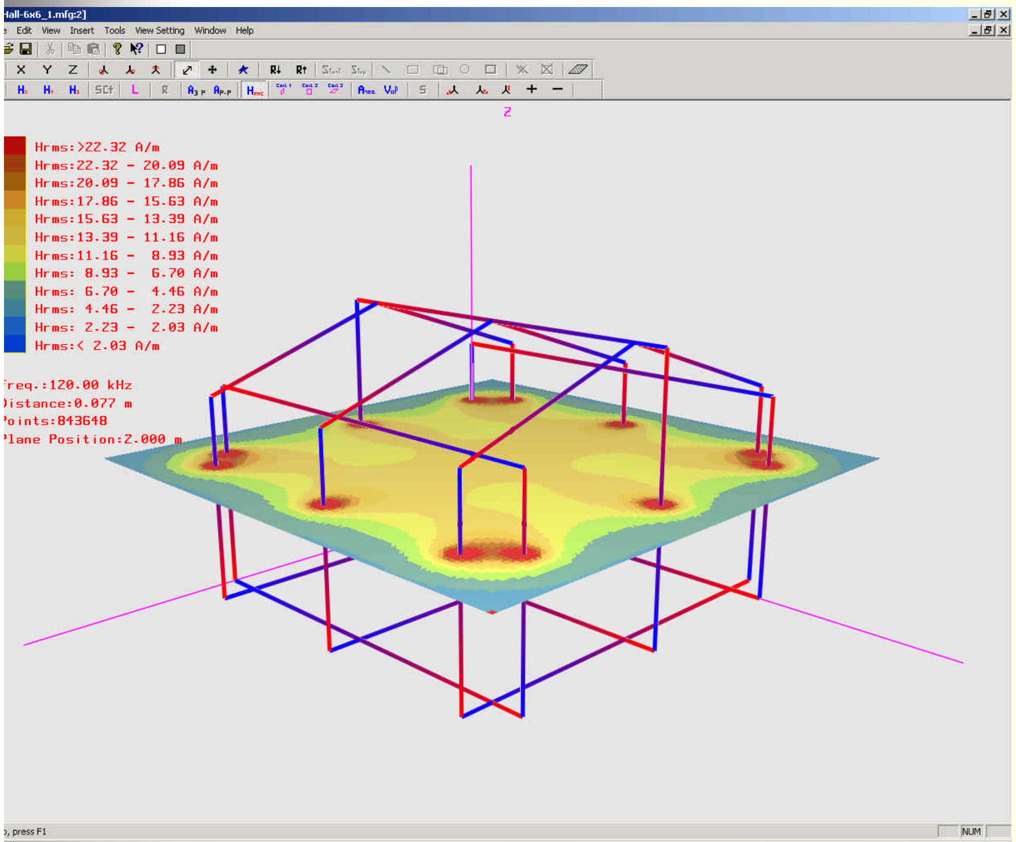
$$k = 2\sqrt{\frac{ar}{(a+r)^2+z^2}} \qquad (k \in [0,1])$$

The field intensity created by several coils is the vector sum of that created by each individual coil

Field Simulation - Options

- Accurate representations of *non-complex* fields can be made using simple equations
  - Advantages:
    - Faster results
    - More accuracy with less memory use
  - Disadvantages:
    - Useful only for very simple field calculations
    - Not feasible to show the influence of eddy currents etc.

Example of field simulation tool



Primary Functions

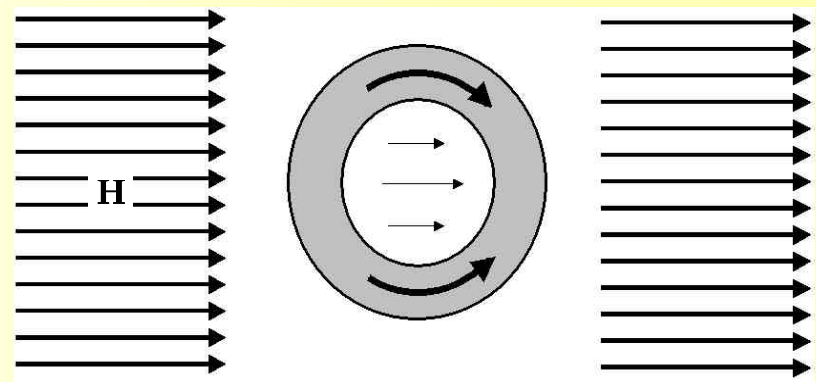
- Visualization of magnetic field vectors (instantaneous values).
- Visualization of the magnetic field distribution in any plane (instantaneous and rms values).
- Visualization of the volume encompassing field magnitudes higher than a reference value.
- Visualization of the induced rms voltage in secondary coils.
- Calculation of currents induced in short-circuit loops.
- Calculation of the self- and mutual inductance of and between coils and short-circuit loops.

Shielding

Objects inside the volume can create shielding effects

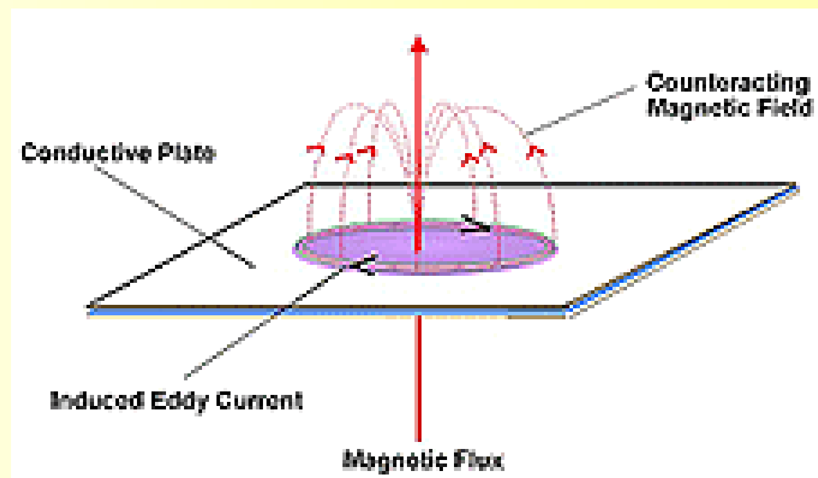
- High permeability (flux shunting)

  The material creates a low-reluctance path for the flux and can “guide” it away from the secondary coils – negligible at 120kHz for most materials



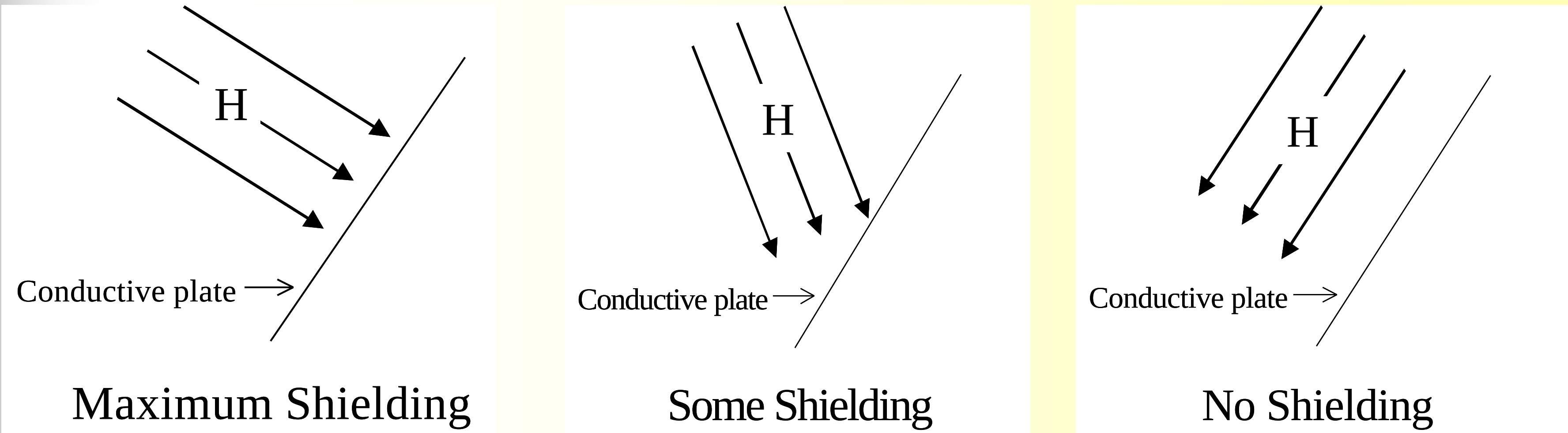
- High conductivity (eddy current shielding)

  Eddy currents induced in the shielding material create a field opposing that which created it (Lenz’s Law)



Shielding

Effect is dependent on the position of the shielding object(s) relative to the orientation of the field created by the primary coils



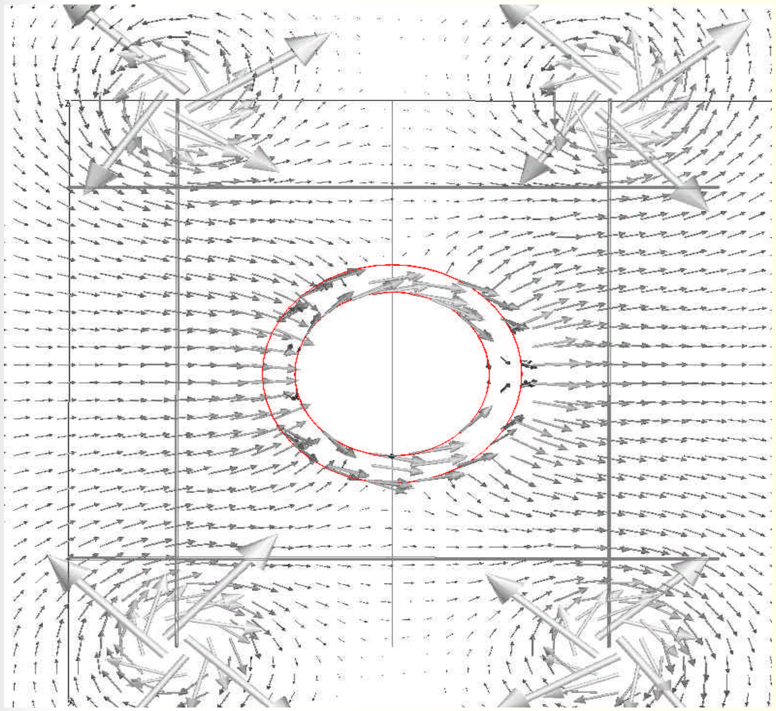
Solution – Rotating field

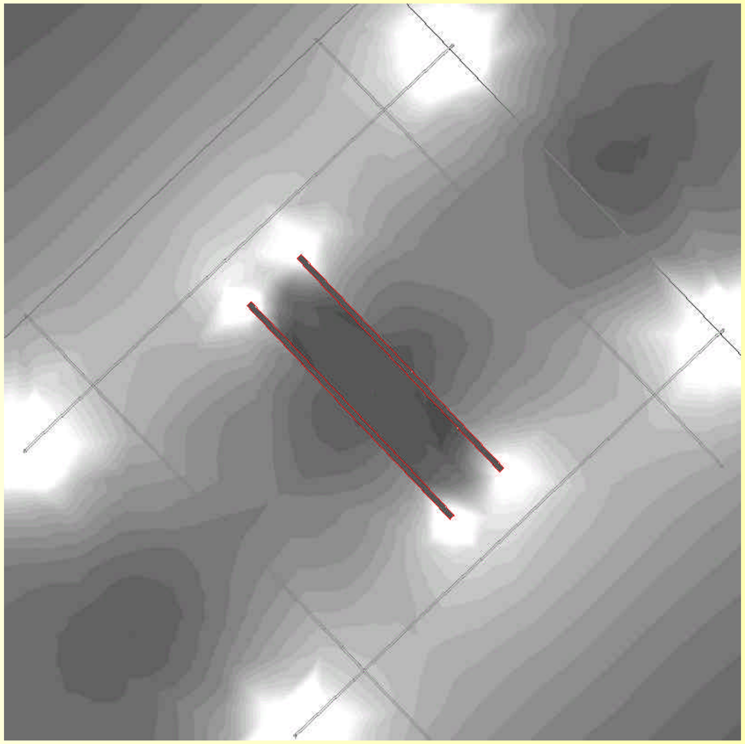
Vary the orientation of the field so that no direction is always shielded

Shielding Analysis

More complex field simulation tools are required to see the interactions between metallic objects and the magnetic field created by the primary coils.

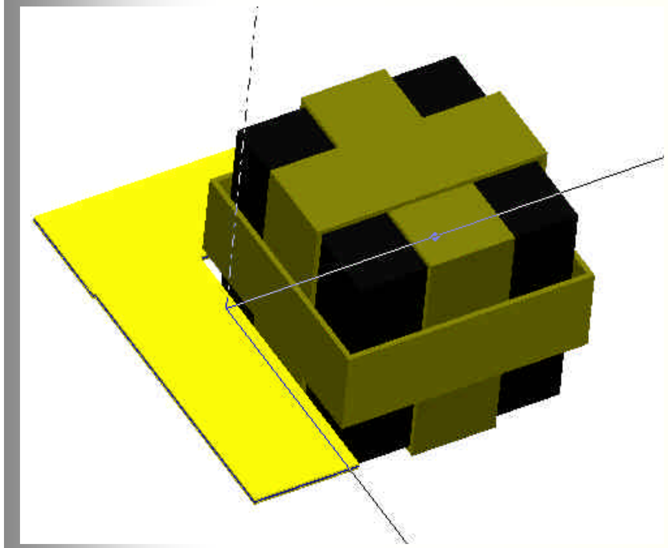
- Results obtained with Ansoft's Maxwell show the effects of shielding, even in highly complex arrangements.

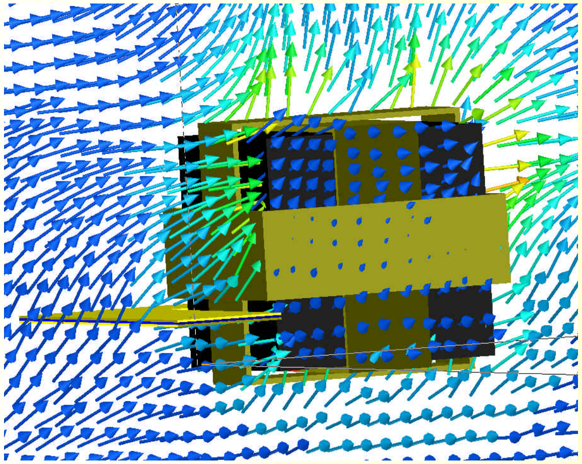


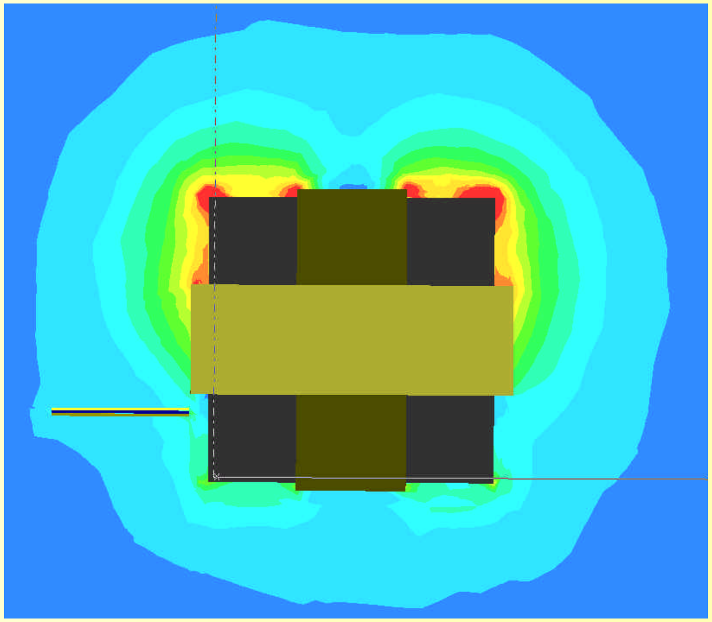


Shielding Analysis

Using Maxwell, we can also see the effects of shielding materials located close to a secondary coil.

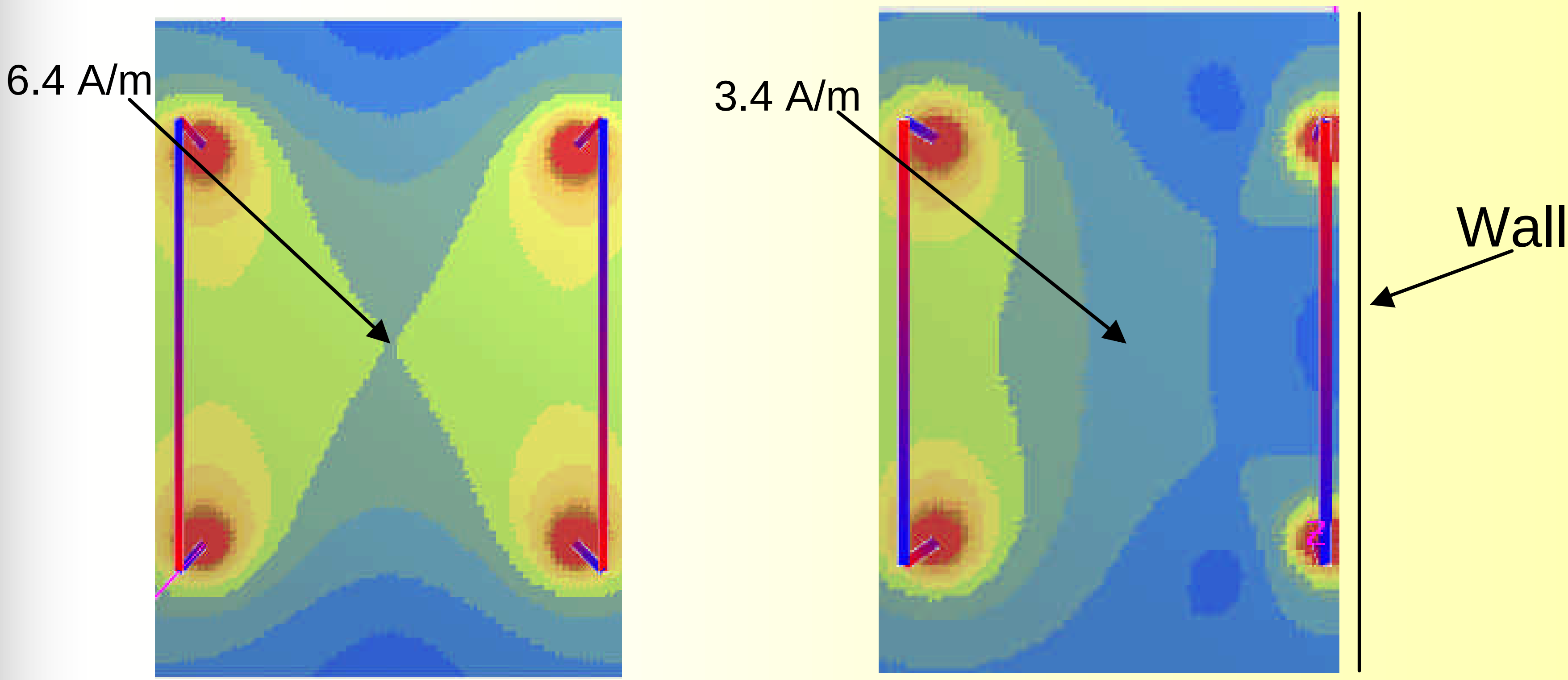






Shielding Analysis

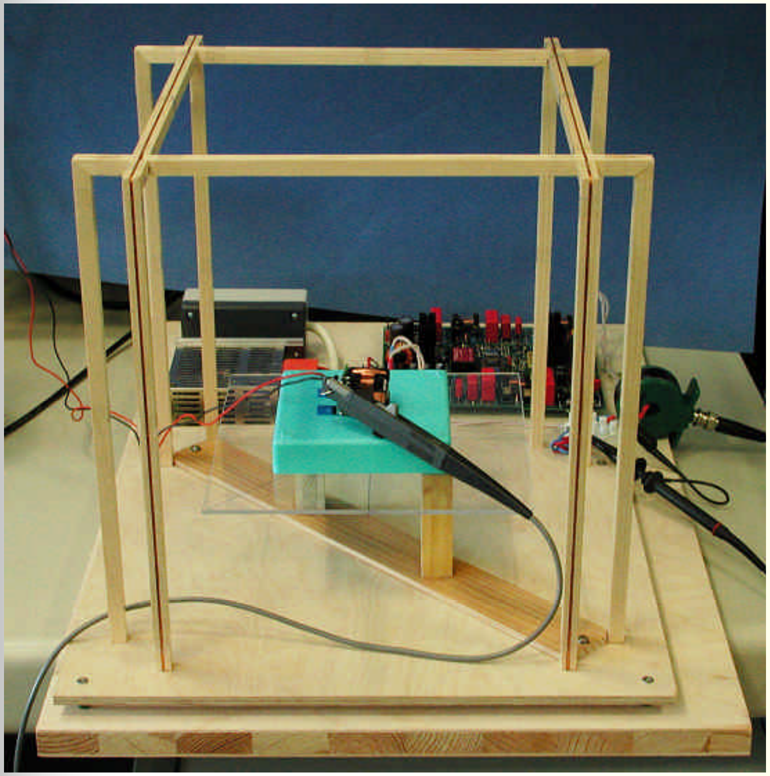
We can also see the effects of field dampening due to walls or floors near the system.



Field distribution around one set of coils 3m x 3m in area, separated by 2.8 m, and carrying 24

Coupling model

A model describing the coupling between primary and secondary coils is necessary to adequately describe the system and predict the power available to the load.



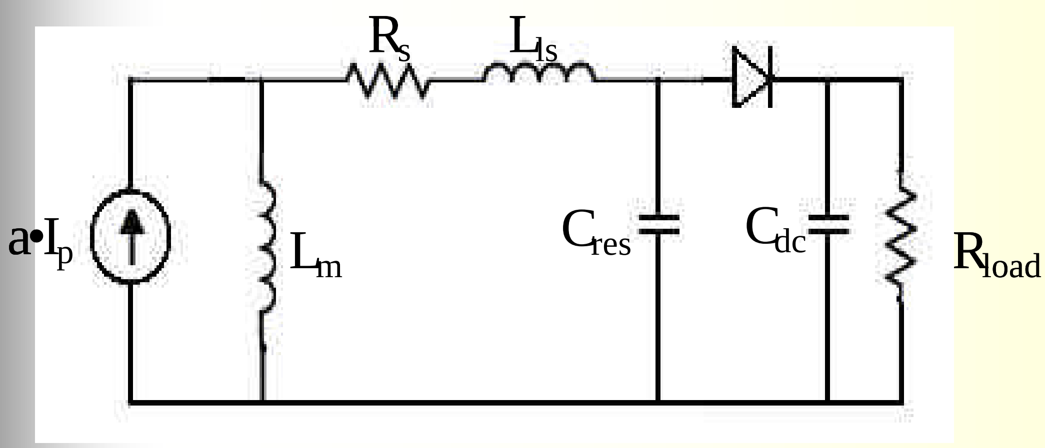
Test setup for verification of coupling model

$I_{primary} = 1.8$ A

$H_{center} = 12$ A/m

Coupling model

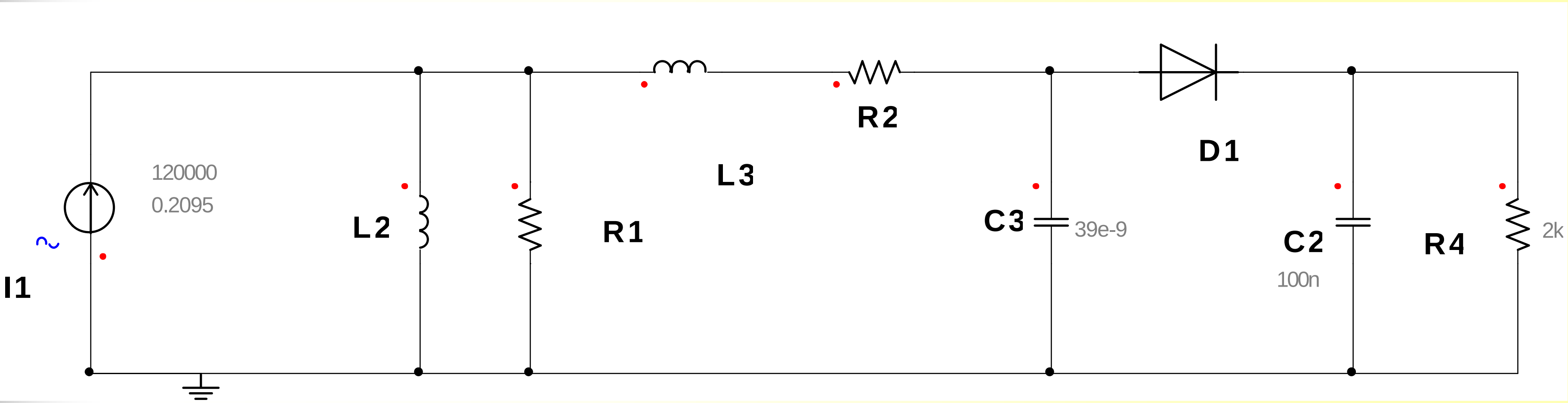
A model similar to that used to describe traditional transformers is sufficient to describe the system.



L_m	= mutual inductance
R_s	= secondary side winding resistance
L_{ls}	= secondary side leakage inductance
C_{res}	= Secondary side resonant capacitance
C_{dc}	= dc-side capacitance
I_p	= Primary side current
a	= Turns ratio (N_1/N_2).
R_{load}	= Load resistance

Coupling model

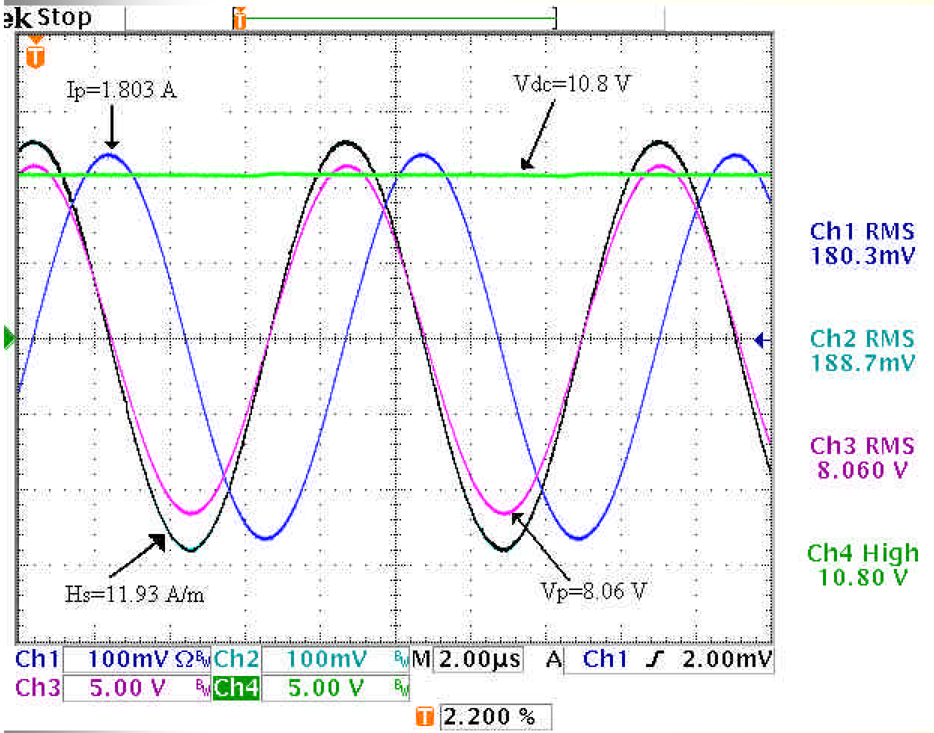
Inductance and resistance values found with the Maxwell simulator can be applied to the coupling model and simulated using the Simplorer simulation tool.

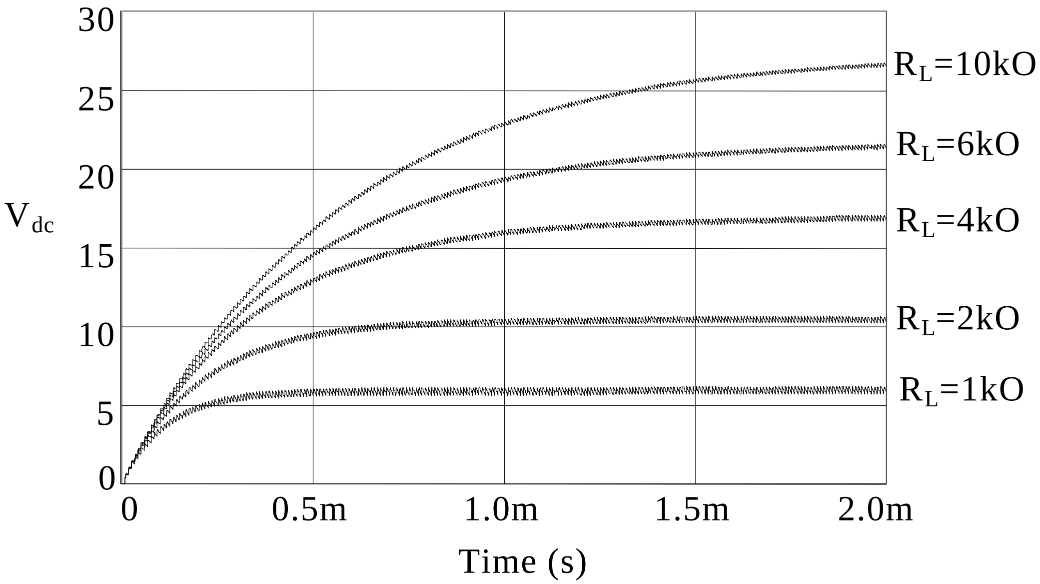


Results have been verified using a laboratory set-up

Coupling model

Comparison of lab test and simulation results





Conclusions

- The characteristics of the magnetic field created by a wireless power system can be clearly and easily shown using simulation
- Simulation greatly simplifies the process of finding the optimum distance between primary-side coils in a wireless power system
- FEA is the best tool for use in describing shielding problems and other complex issues, but a simplified simulation tool can be used to examine less complex field distributions
- The Maxwell and Simplorer simulation tools together provide a complete package for the development and analysis of a coupling model describing a wireless power system

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Further Information also at www.teicon.com