FREEDM SYSTEMS CENTER

# *Dynamic Wireless Charging for Electric Vehicles: Approaches for Reflexive Field Containment Using Reactive Components*

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# Dynamic Wireless Power Transfer

## Wireless Power Transfer: An Alternative to Conductive Charging.

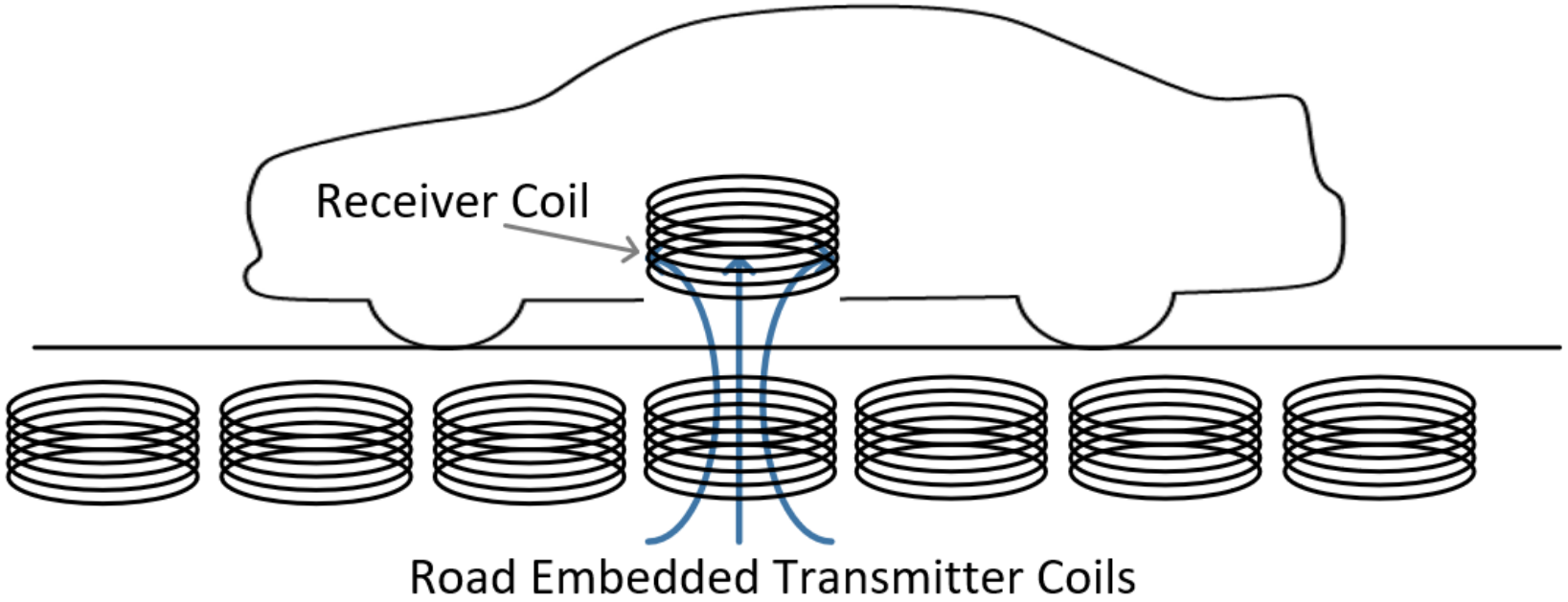
- Source to load efficiencies of over 90% are possible at coupling coefficients of 0.2.


## Why Dynamic Wireless Power Transfer?

- Increased range and reduced charging times.
- Reduced vehicle energy storage requirements

Electric-vehiclenews.com. (2018). UK To Test Dynamic Wireless Charging For Electric Cars. [online] Available at: http://www.electric-vehiclenews.com/2015/08/uk-to-test-dynamic-wireless-charging.html

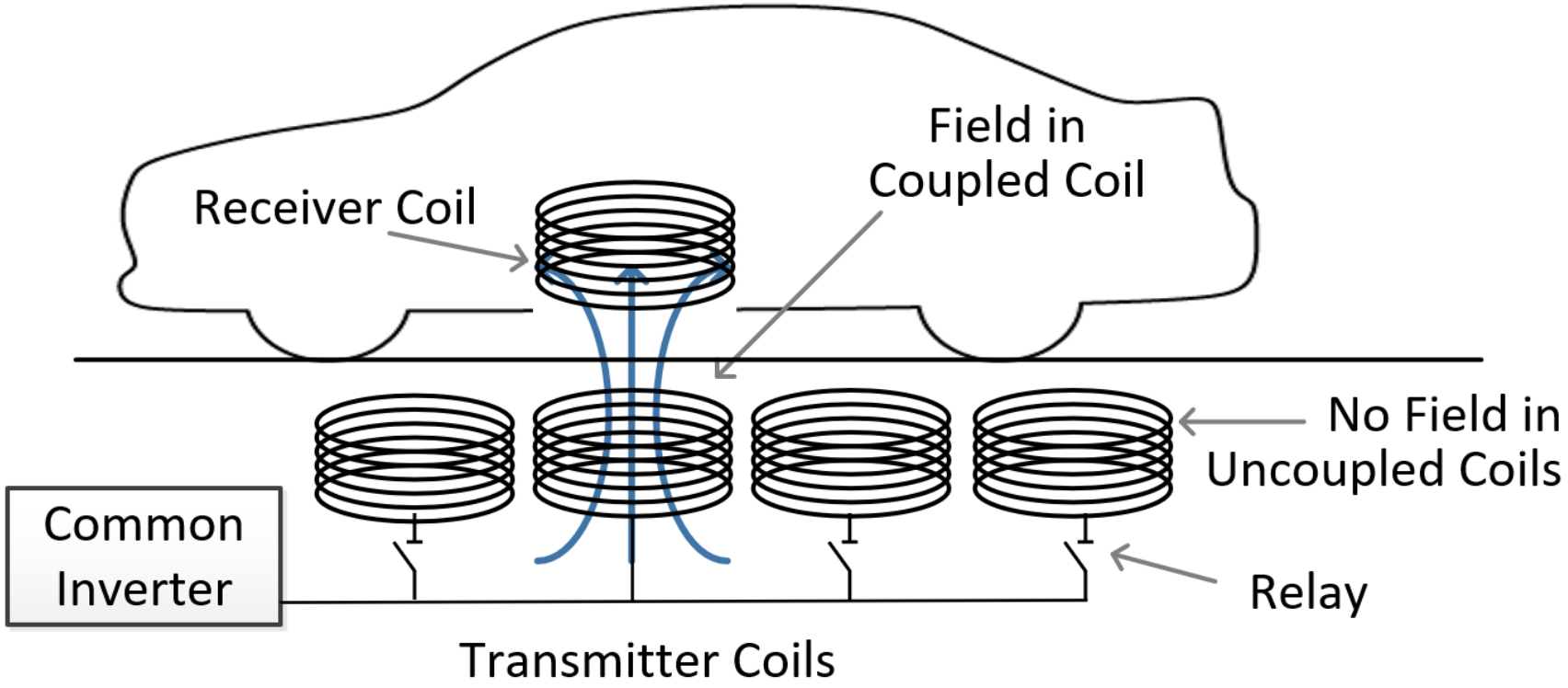
# Dynamic Wireless Power Transfer




Dynamic WPT may be accomplished through an array of segmented transmitting coils that sequentially couple to a passing receiving coil, thus isolating the field emissions to the coupled coil. Challenges include:

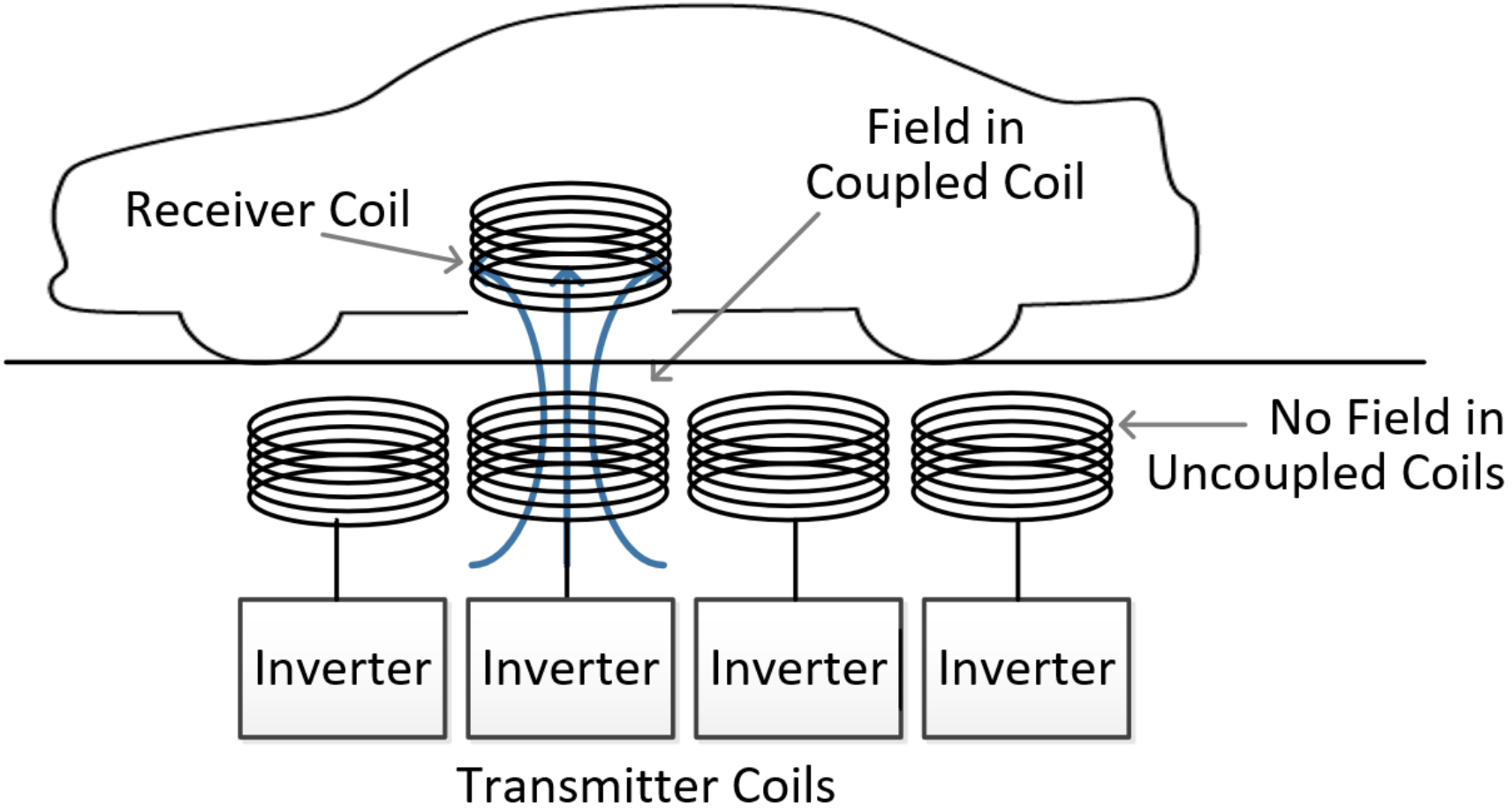
- Precise Receiver Position Feedback is required.
- Efficient and fast methodology to selectively energize coupled coil.

# Dynamic Approach One



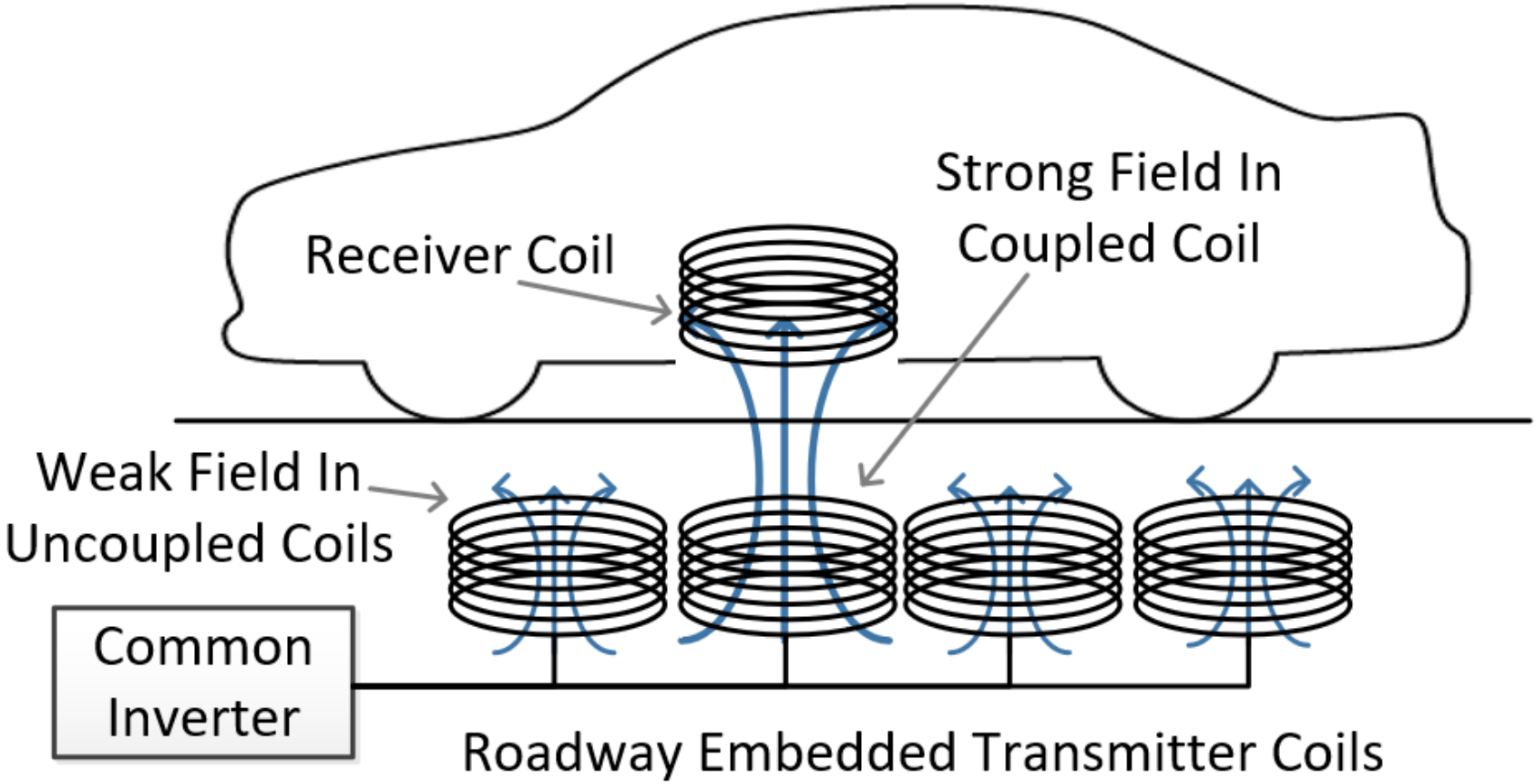

Position sensor and relays for power flow control to coupled coils.

# Dynamic Approach Two




Power each coil with a dedicated inverter (cost prohibitive in large applications).

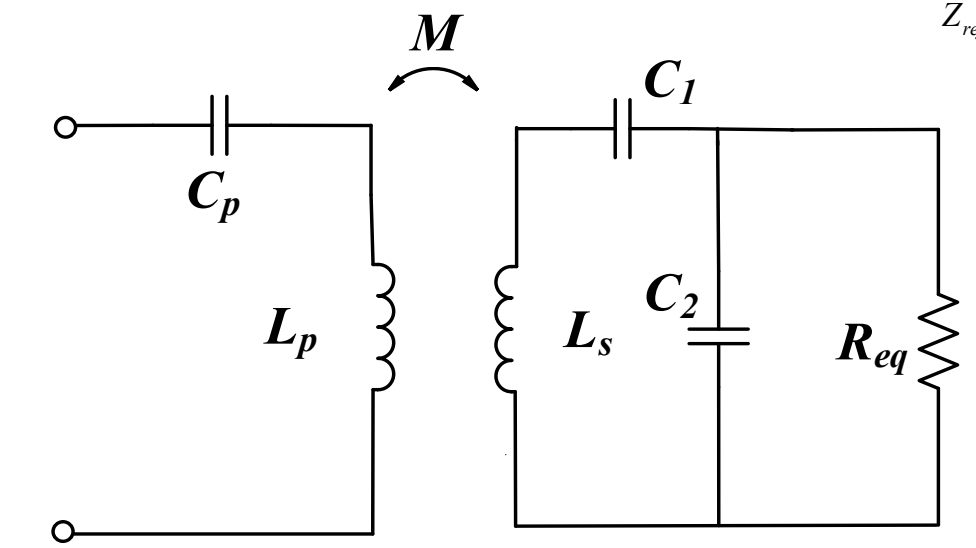
# Dynamic Approach Two

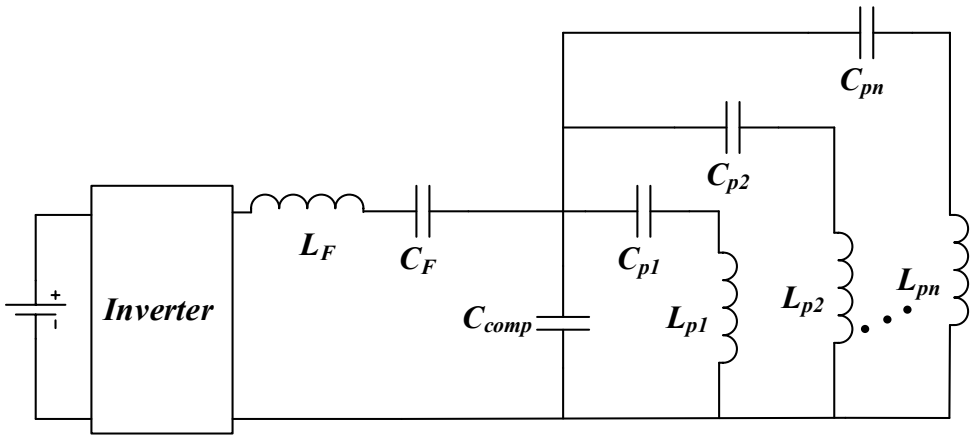



Exploit reflected impedance of receiving coil to control emitted field reflexively

# Reflexive Field Containment Approach

## Series-Parallel-LCC




**Allows for Segmented TX Coils**

$$Z_{reflected} = \frac{(\omega M)^2}{Z_s} = \frac{M^2 R_{eq}}{L_s^2} \cdot n^2 - n \cdot j \frac{\omega M^2}{L_s} = \frac{\omega M^2}{L_s}(Q_{Total} - n \cdot j)$$

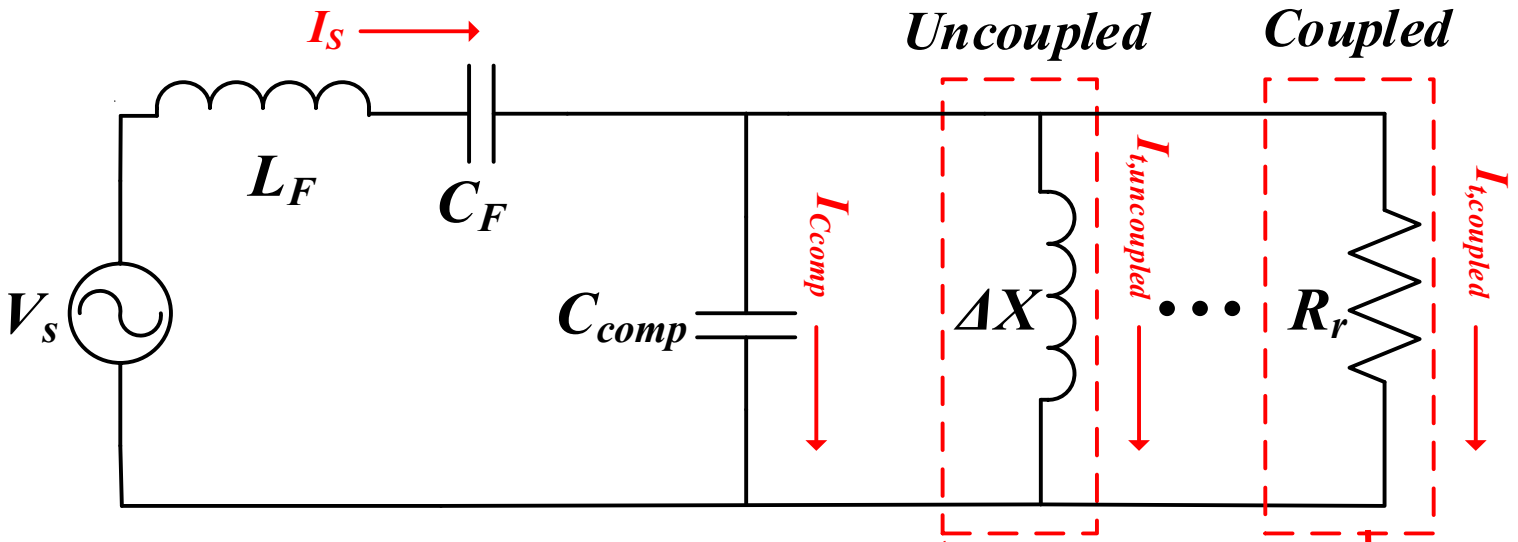
### *When Uncoupled…*

- Large uncompensated reactance In uncoupled TX coils

### *When Coupled…*

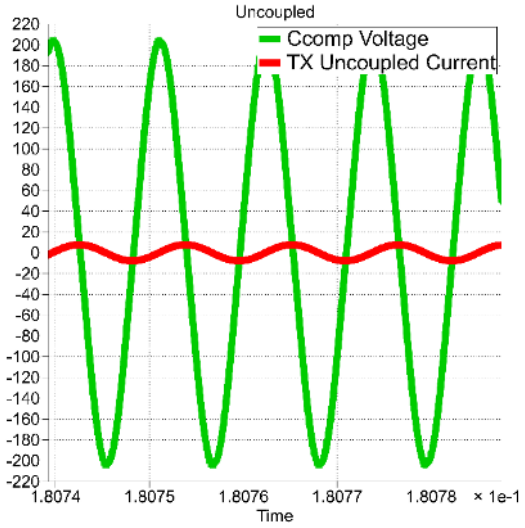
- Reflected reactance brings TX coil into resonance
- Current flow is boosted

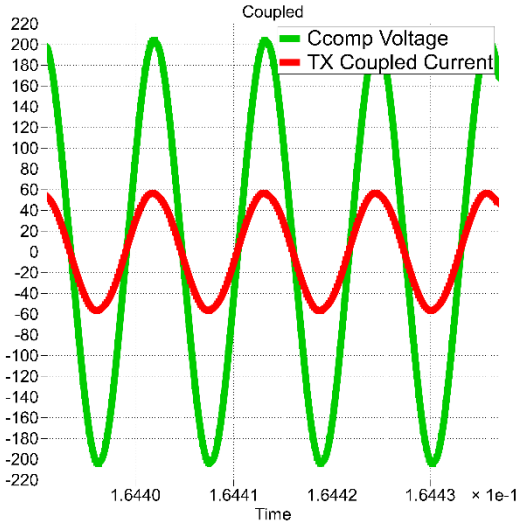
# Transmitter Design



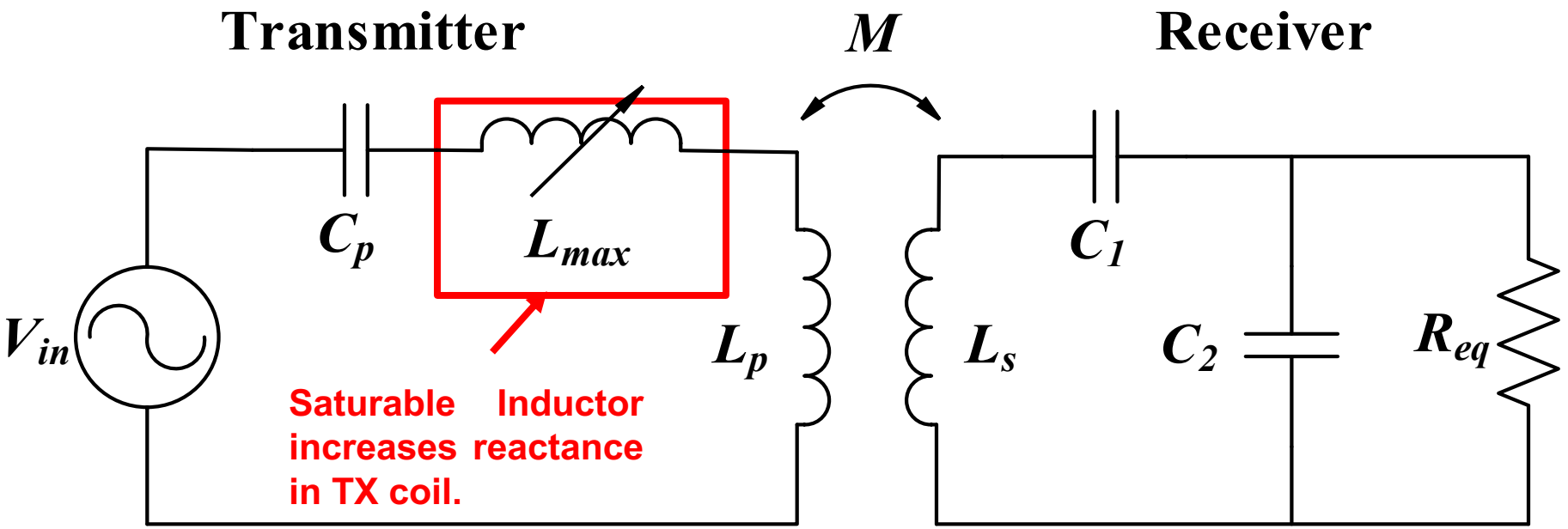

$$I_{t,uncoupled} = \frac{V_s}{j\Delta X}$$

$$I_{t,coupled} = \frac{V_s}{R_r}$$



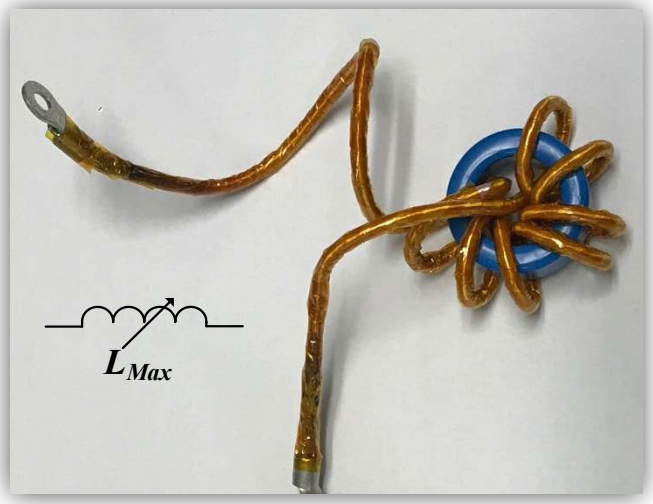



# Improving Field Containment

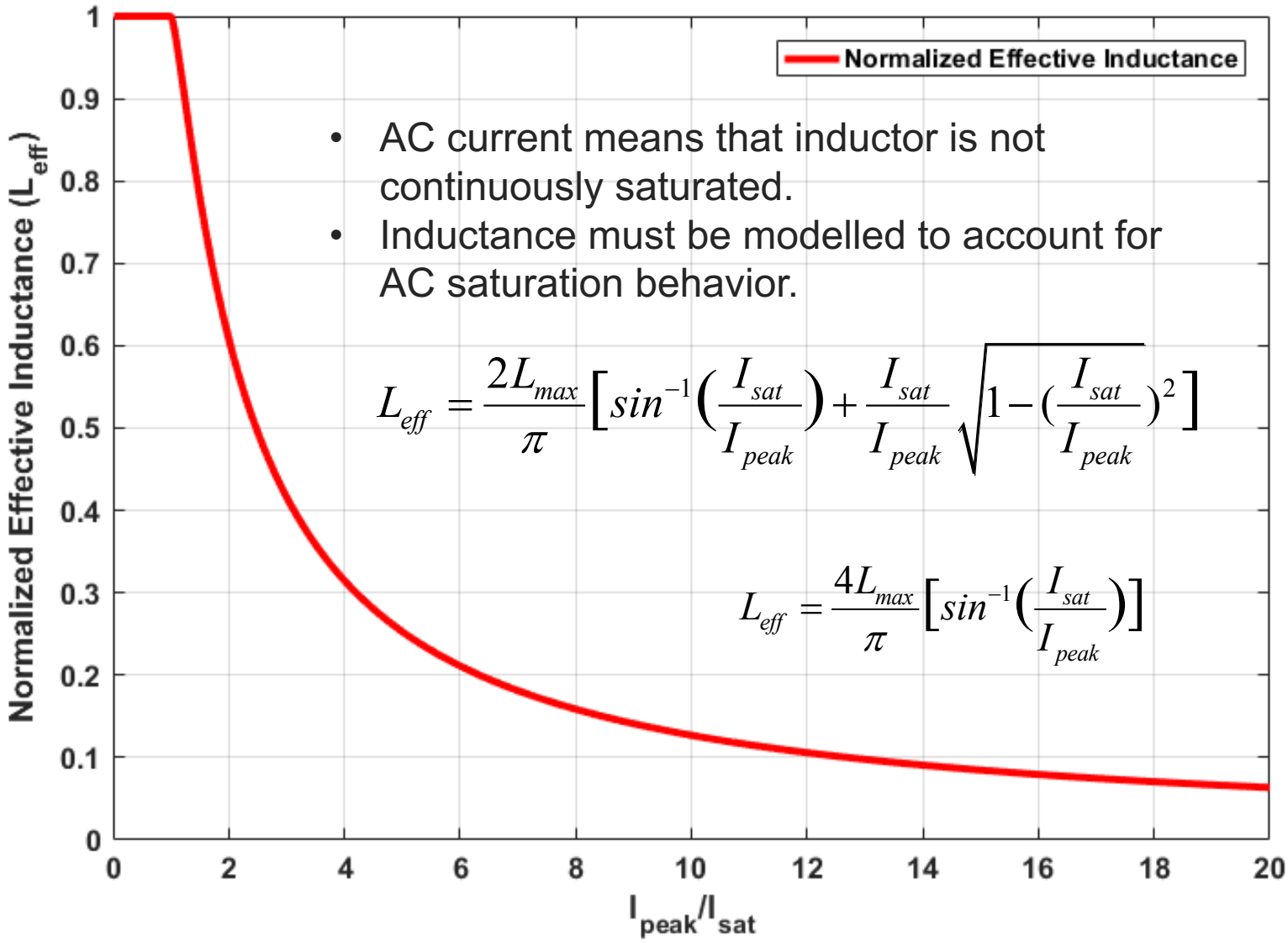



**The Saturable inductor:**

- Maximizes the difference between coupled and uncoupled currents in the TX coil.
- Saturates as the system becomes coupled.
- Improves system current gain (and field attenuation performance).



# Saturable Inductor Characteristics



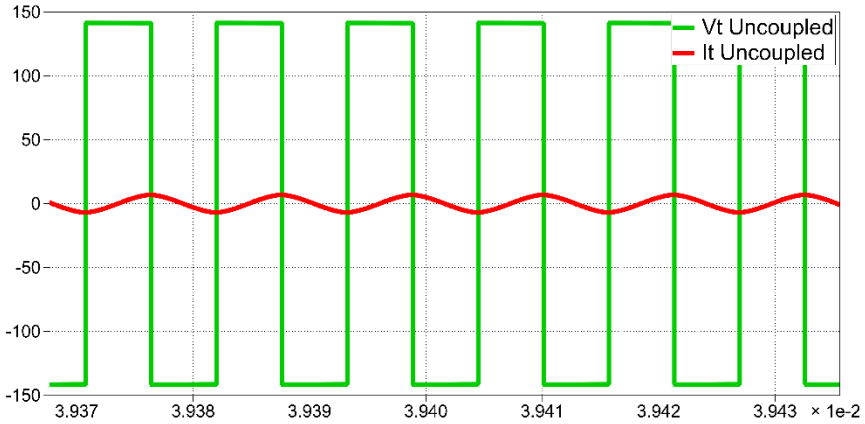

- AC current means that inductor is not continuously saturated.
- Inductance must be modelled to account for AC saturation behavior.

$$L_{eff} = \frac{2L_{max}}{\pi}\left[sin^{-1}\left(\frac{I_{sat}}{I_{peak}}\right) + \frac{I_{sat}}{I_{peak}}\sqrt{1-\left(\frac{I_{sat}}{I_{peak}}\right)^2}\right]$$

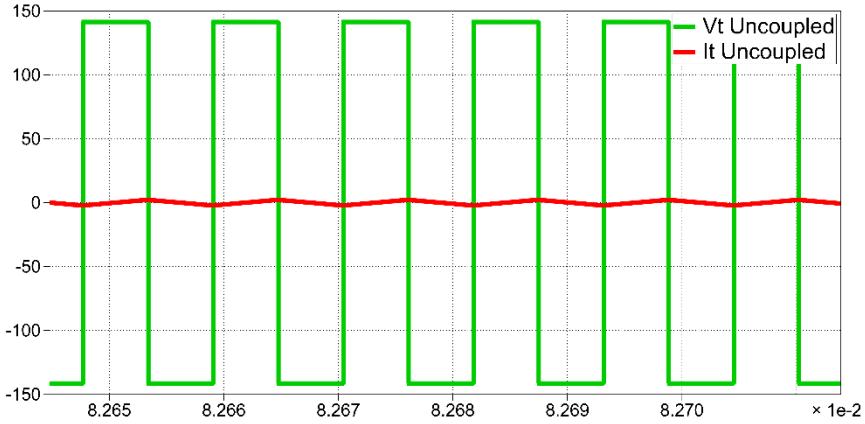
$$L_{eff} = \frac{4L_{max}}{\pi}\left[sin^{-1}\left(\frac{I_{sat}}{I_{peak}}\right)\right]$$

# Simulation – Comparison to Reference System

## Reference System

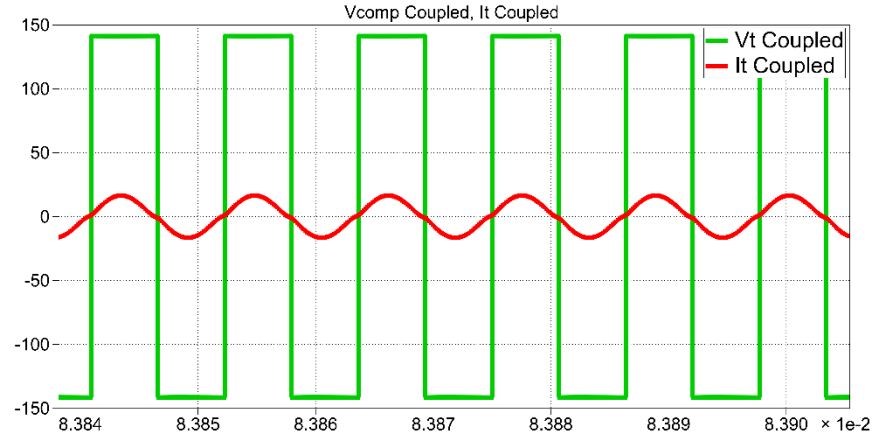



## System With Saturable Inductor



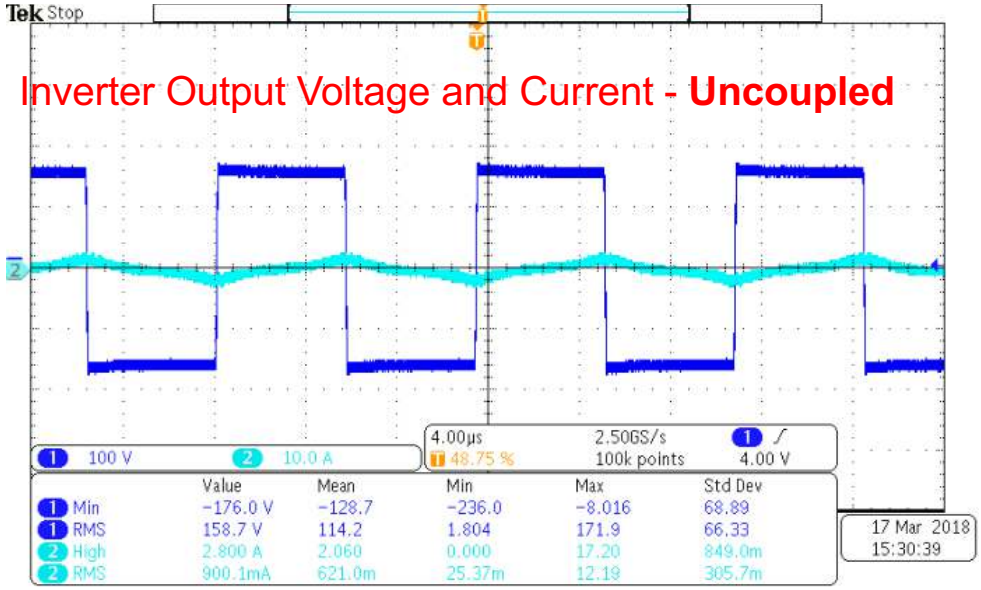


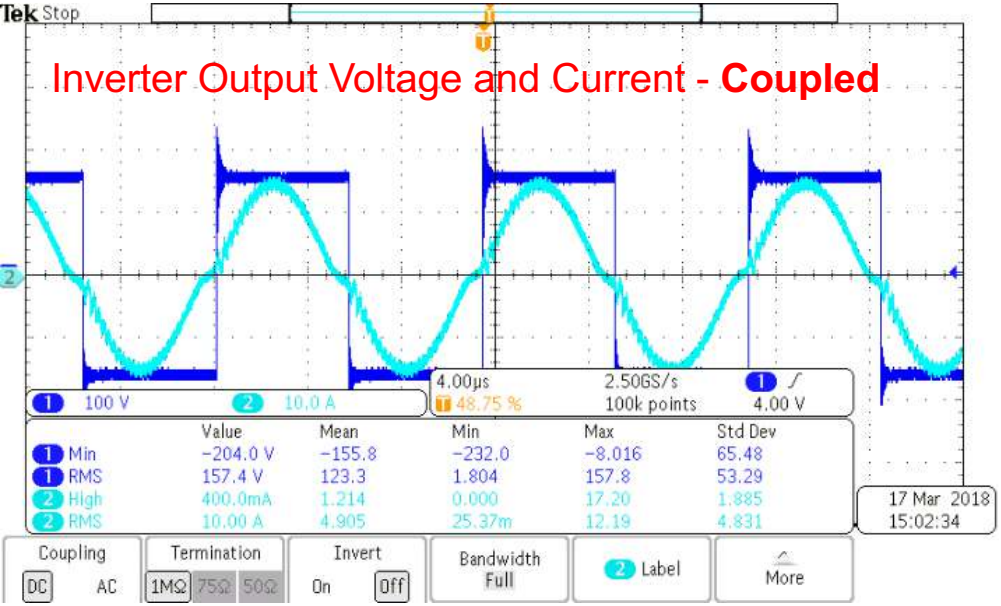
## Current gain 11




## Current gain 3

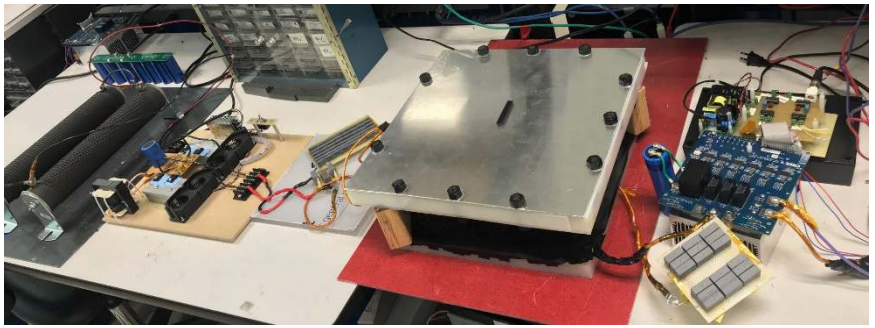
# Hardware Validation




| Transmitter (TX)* | |
|---|---|
| $L_p$ | 190*uH* |
| $C_p$ | 22.65*nF* |
| $L_{max}$ | *180uH* |
| $L_{eff}$ | *23uH* |
| $C_{sat}$ | *143nF* |

| Receiver System | |
|---|---|
| $L_s$ | 237*uH* |
| $C_1$ | 16.56*nF* |
| $C_2$ | 82.81*nF* |
| $n$ | 6 |
| $R_{Load}$ | 7.5 |



| | |
|---|---|
| **Input Voltage** | 171.1 V |
| **Input Current** | 8.65 A |
| **Input Power** | 1480 W |
| **Output Power** | 1208.4 W (95.2^2/7.5) |
| **Efficiency** | 81.6% |
| **Current Gain** | **11.1** |

# Conclusion

- Entirely passive field containment approach for the dynamic charging of electric vehicles.
- Builds upon previously published work.

# Impacts

- Aid in the proliferation of electric vehicles.
- Aids in the meeting of field emissions standards.
- Technology may be used in: autonomous vehicles and consumer electronics.