Comparative Implication and Analysis of Inductive & Capacitive Wireless Power and Data Transfer in USB

Pooja Sharma*
E&Tc & G.S.Moze COE Balewadi,
Savitribai Phule Pune University

Jayshree Pande
E&Tc & G.S.Moze COE Balewadi,
Savitribai Phule Pune University

Archana Singh
E&Tc & G.S.Moze COE, Balewadi,
Savitribai Phule Pune University

Abstract— ***Wireless Power Transfer (WPT) is the process of transferring power from one circuit onto another without passing through any manmade conductive elements interconnecting them. Several schemes for wireless power transfer exists – Inductive, Capacitive, Laser, Microwave etc. This paper explains the inductive Power Transfer (IPT). This paper also includes analysis that predicts fundamental limitations on the maximum achievable efficiency for a given amount of coupling capacitance and is used to find the optimum circuit component values and operating point. The paper describes automatic tuning loops that ensure the circuit operates at the optimum frequency and maximum efficiency over a wide range of coupling capacitance and load conditions. Here, the Universal Serial Bus (USB) standard to the contactless domain by combining bidirectional data communication with a capacitive power transfer interface. We addresses the power transfer with analysis, based on a secondary side phase feedback series resonant topology. This paper gives the advantage of simple circuitry to regulate output voltage over large parametric variations of the capacitive interface. Secondly this paper presents the data communication analysis, simulations and experiment where differential mode voltage containing the data information rides on top of the larger power voltage. An experimental prototype was built to deliver 1.25W of power with 53% overall efficiency over a total of 300pF capacitance with an area of 52cm^2, also realizing 100Mb/s bidirectional data communication.***

Keywords— contactless charging; wireless power standard Qi; wireless power transfer, USB, Automatic tuning loops, data communication, electrostatic induction, electromagnetic induction

I. INTRODUCTION

With the formation of the Qi standard[6], wireless charging of portable devices such as smartphones, ipads, and laptop computers is gaining momentum in changing the way we provide power to devices. The Qi standard is based on an inductive interface, shared between the power transmitter, such as powermat[7], and a portable device, such as a mobile handset. Power is transfered wirelessly through magnetic fields. However, another approach exists in the form of a capacitive interface, formed by two metal plates separated by a thin layer of isolation[8]. In comparison to an inductive interface, a capacitive interface is more limited in separation distance. With a receiving device resting directly on the charger, this need not be a limitation. In favor of capacitive charging, the capacitive interface has much reduced external fields, a single resonance, and no need for substantial reactive magnetizing current[9].

The main attractiveness of wireless charging is its unconventional way of charging, deviating from the mainstream of cables and wires. However, one important aspect still absent is the data communication. Existing capacitive power and data technology is either very near field with μm range for chip-to- chip applications[9],[12] or for biomedical applications where the data rate is low[9],[10]. This work fully extends the USB interface to the contactless domain. The USB port provides both power and data channels to devices. As such, this work accomplishes both aspects with similiar specifications to those of the USB standard[1],[11], watts of power and hundreds of megabits to gigabits of data.

Wireless power delivery is gaining increasing attention for powering and charging portable devices including smart phones, cameras, and laptop computers. The predominant solution today uses an inductive [2], [3] interface between a charging station, acting as the transmitter, and a receiver, typically a portable device. Both the transmitter and receiver are fitted with electrical coils. When brought into physical proximity, power flows from the transmitter to the receiver. Here we examine an alternative approach that uses a capacitive, rather than inductive interface to deliver power. In the capacitive interface the field is confined between conductive plates, alleviating the need for magnetic flux guiding and shielding components that add bulk and cost to inductive solutions [4].

II. WIRELESS POWER TRANSFER

Wireless Power Transfer (WPT) is the process of transferring power from one circuit onto another without passing through any manmade conductive elements interconnecting them. Several schemes for wireless power transfer exists – Inductive, Capacitive, Laser, Microwave etc. Of these, Inductive Power Transfer (IPT) is the most popular.

Inductive – Transmitter coil that creates a magnetic field; receiver coil picks up the magnetic field and generates an electric current.

Magnetic resonance – Both a transmitter and receiver coil operating at resonance.

Capacitive – Transmitter plate generates an electric field via high voltage; receiver plate receives this voltage and rectifies this as a DC output.

Based on the mode of coupling between the transmitter and the receiver, wireless power transfer techniques can be classified into the following:

1. Electromagnetic induction (Resonant Inductive Power Transfer)
2. Electrostatic induction (Resonant Capacitive Power Transfer)
3. Far field transfer techniques (Laser and Microwave Power Transfer)

A. Electromagnetic induction

Electromagnetic Inductive Power Transfer (IPT) is a popular technique of transferring power wirelessly over a short range as shown in fig.1. This technique of transferring power derives its capability from the two fundamental laws of physics: Ampere's law and Faraday's law. The functioning of such IPT systems is based on the changing magnetic field that is created due to alternating currents through a primary that induce a voltage onto a secondary coupled by means of air. In order to improve the efficiency of power transfer, resonant mode coupling of the coils is established by means of capacitive compensation. This technique is one of the most popular for wireless power transfer and has found vast applications including powering consumer devices, biomedical implants, electric mobility, material handling systems, lighting applications and contactless underwater power delivery among many others.

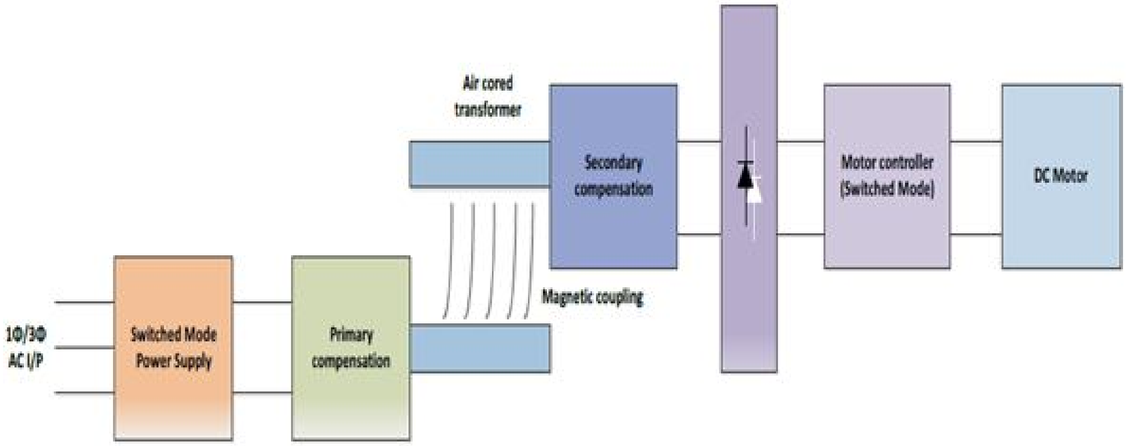

Figure 1: An IPT system for powering an EV

B. Electrostatic induction

Capacitive Power Transfer (CPT) is a novel technique used to transfer power wirelessly between the two electrodes of a capacitor assembly as shown in fig.2. It is based on the fact that when high frequency ac voltage source is applied to the plates of the capacitor that are placed close to each other, electric fields are formed and displacement current maintains the current continuity. Thus, in this case the energy carrier media is the electric field and hence the dual of IPT.

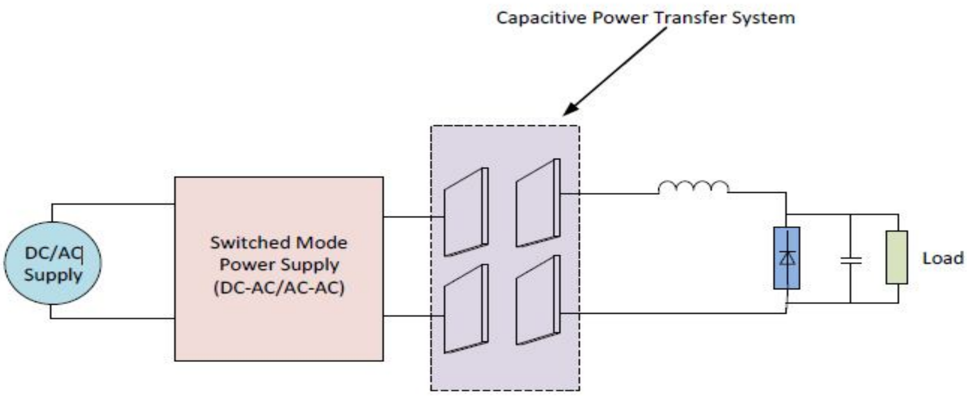

Figure 2: Electrostatic CPT system

C. Comparisons

Table 1 -- Comparison between inductive, resonance and inductive

Characteristic	Inductive	Resonance	Capacitive
Efficiency	Comparable to traditional	Comparable to traditional	Comparable to traditional
Power Scalability	Highly	Slightly	Constrained by charge surface area
Operating frequency	< 500kHz	kHz – MHz range	Varies
Thermal Footprint	Dependent on efficiencies	Dependent on efficiencies	None
Multiple Devices	One to One relationship	Yes	One to One relationship
Z - Spatial Freedom	< 1cm	< 4cm	< 1cm
Cost Points	Micro & coils	Complex Rx	Electrodes, amplifiers, transformers

Some of the features that CPT has compared to IPT are:

1. Energy transfer can still continue even on the introduction of a metal barrier as it would result in a structure consisting of two capacitors in series.

2. Most electric fields are confined within the gap between the capacitors and hence EMI radiated and power losses are low.

3. The requirement for bulky and expensive coils doesn't exist and hence, the circuit can be made small.

D. WIRELESS POWER CONTIRUM, Qi

Qi is Chinese word and it is commonly known as "chi". Qi is translated as "natural force", "life force" or "energy flow".With the formation of the Qi standard[6], wireless charging of portable devices such as smartphones, ipads, and laptop computers is gaining momentum in changing the way we provide power to devices. The Qi standard is based on an inductive interface, shared between the power transmitter, such as powermat[7], and a portable device, such as a mobile handset. Power is transfered wirelessly through magnetic fields.

It has features:

1. Complete supply chain
2. Power scalability to 120W
3. Resonance (via Power by Proxie & Fulton)
4. Distances scalable up to 4cm
5. Operating frequency 105 – 205 kHz

E. SYSTEM OVERVIEW

For wireless power transfer if we need to charge mobile then we require base station and mobile device. Base Station contains one or more transmitters. Transmitter receives power signal from system and provides power to receiver. Mobile Device contains a receiver that provides power to a load (e.g. a battery) and the receiver provides control information to transmitter. After receiving the control signal from receiver the transmitter will give constant supply to the transmitter.

In power conversion is converting electric energy from one form to another, converting between AC and DC, or just changing the voltage or frequency, or some combination of these. A power converter is an electrical or electro-mechanical device for converting electrical energy. This could be as simple as a transformer to change the voltage of AC power, but also includes far more complex systems. The term can also refer to a class of electrical machinery that is used to convert one frequency of alternating current into another frequency. Power conversion systems often incorporate redundancy and voltage regulation. In power pickup converted DC power will be received and transfer it to the load.

Control is a mechanism to regulate the operation of system. Receiver controls the power to the output load to the need of the mobile device (required power) and to the desired operation point (e.g. output current, voltage).Transmitter adapts power transfer to the need of the receiver (required power) and to the desired operation point (e.g. primary coil current).

It contains communication which modulates and demodulates the message signal from control as shown in fig. 3. Receiver sends messages to provide control information to the transmitter and by load modulation on the power signal. Transmitter receives messages to receive control information from the receiver and by de-modulation of the reflected load.

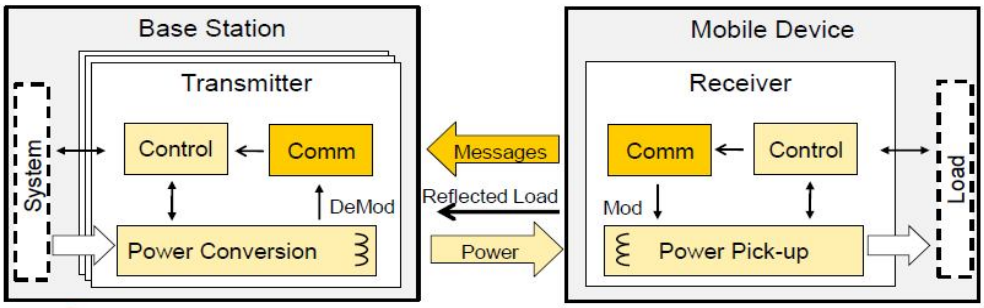

Figure 3: System overview

1) *Communication (Data-Format):* Fig. 4 shows communication data-format. We have speed of 2 Kbit/s.Bit-encoding is bi-phase, Byte encoding contains start-bit, 8bit data, parity-bit, stop-bit. Packet Structure in which data transfers contains Preamble (>= 11bit), Header (1 Byte) indicates packet type and message length, Message (1 .. 27 Byte). One complete message per packet is send and payload for control checksum (1 Byte).

2) *Communication and Control:* It consists of four steps as shown in fig. 5.

Start: Transmitter provides signal and senses for presence of an object (potential receiver) and Receiver waits for signal.

Ping: Receiver indicates presence by communicating received signal strength. Here,transmitter detects response of receiver

Identification & Configuration: Receiver communicates its identifier and required power and Transmitter configures for power transfer.

Power Transfer: Receiver communicates control data and Transmitter adapts power transfer.

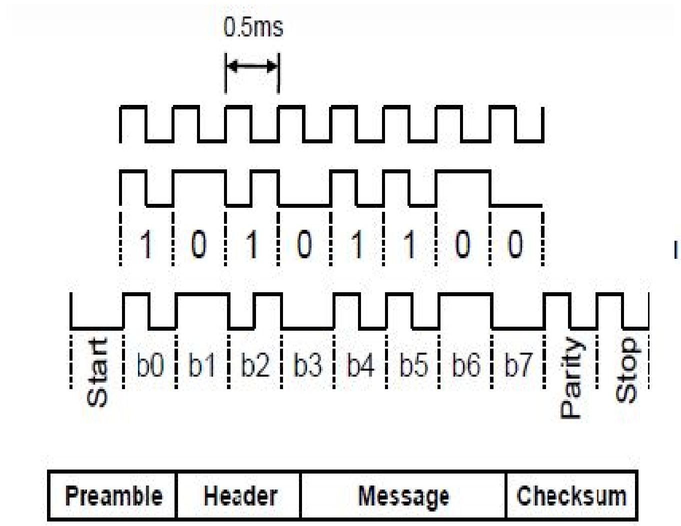

Figure 4: Communication (Data-Format)

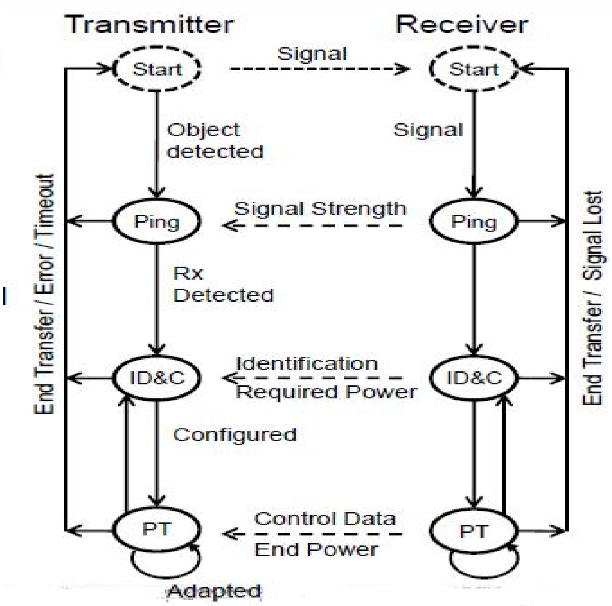

Figure 5: Communication & Control

3) Foriegn Object Detection: Foriegn object detection in done in inductive power transfer as shown in fig. 6. The presence of foreign objects can absorb energy from the magnetic field, causing heating of the object. The system must account for all power to detect the presence of a foreign object.

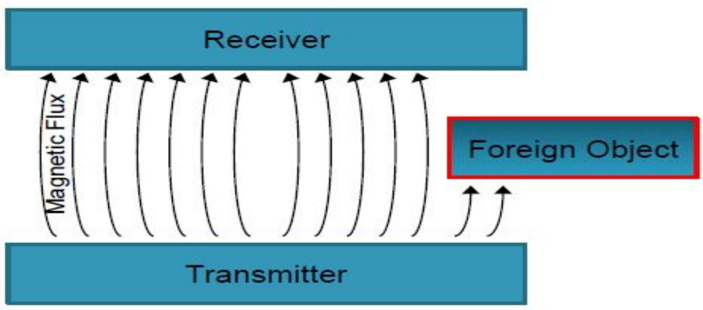

Figure 6 : Foreign Object Detection

III. WIRELESS POWER AND DATA TRANSFER THROUGH USB

A. WIRELESS POWER AND DATA TRANSFER

The main attractiveness of wireless charging is its unconventional way of charging, deviating from the mainstream of cables and wires. However, one important aspect still absent is the data communication. Existing capacitive power and data technology is either very near field with µm range for chip-to- chip applications or for biomedical applications where the data rate is low. This work fully extends the USB interface to the contactless domain. The USB port provides both power and data channels to devices. As such, this work accomplishes both aspects with similiar specifications to those of the USB standard, watts of power and hundreds of megabits to gigabits of data. A simplified block diagram of the power and data transfer is illustrated in Fig.7. Here the differential mode voltage (DM) provides the data communication to the receiver while the larger common mode (CM) voltage delivers power. The top side circuitry transmits data from the primary side to the secondary side. At the same time, an independent data channel is on the bottom delivering data from the secondary side to the primary side.

B. CAPACITIVE POWER TRANSFER ANALYSIS

Fig.8 shows the detailed power and data transfer circuitry. Each part of the circuitry will be explained and analyzed in detail in the paper. The power transfer section is a series resonant converter (SRC) with active H-bridges on both the primary side and the secondary side. The primary side Hbridge has a low voltage supply of 5V , compatible with the USB supply voltage. This is followed by a (1 : 10) transformer to boost the voltage level to 50V to allow for efficient power delivery. The (1 : 10) transformer contains large leakage inductance which is incorporated into the resonant inductance used to tune out the capacitive interface. This allows for a low impedance path along which ac current can flow to deliver power.With the resonant inductance as a parameter, the switching frequency and therefore the impedance of the capacitor can be adjusted in order to provide a safe voltage across the capacitive interface. The secondary side architecture is nearly identical to the primary side, except the H-bridge is connected to a load instead of to a supply voltage. Furthermore, separate independent inductors are incorporated into the secondary side. These independent inductors are used both for increasing the overall resonant inductance and for providing a method for sensing current. Current sensing in the inductor

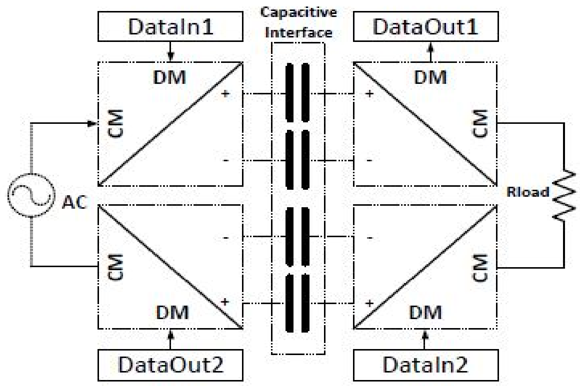

Figure 7: Simplified Power and Data Transfer Block Diagram

is done by low passing the secondary winding voltage on the inductor. With regard to the gate drive signal, the primary side gate drive is done by a system clock running nominally at 2.3MHz and the secondary side gate drive is phase delayed with respect to the tank current. The phase shift is denoted -Φ2. The notation Φ 1 is the phase difference between the phase of the primary side H-bridge and the tank current. Output voltage is regulated to 5V by sensing the output voltage and modulating -Φ 2.

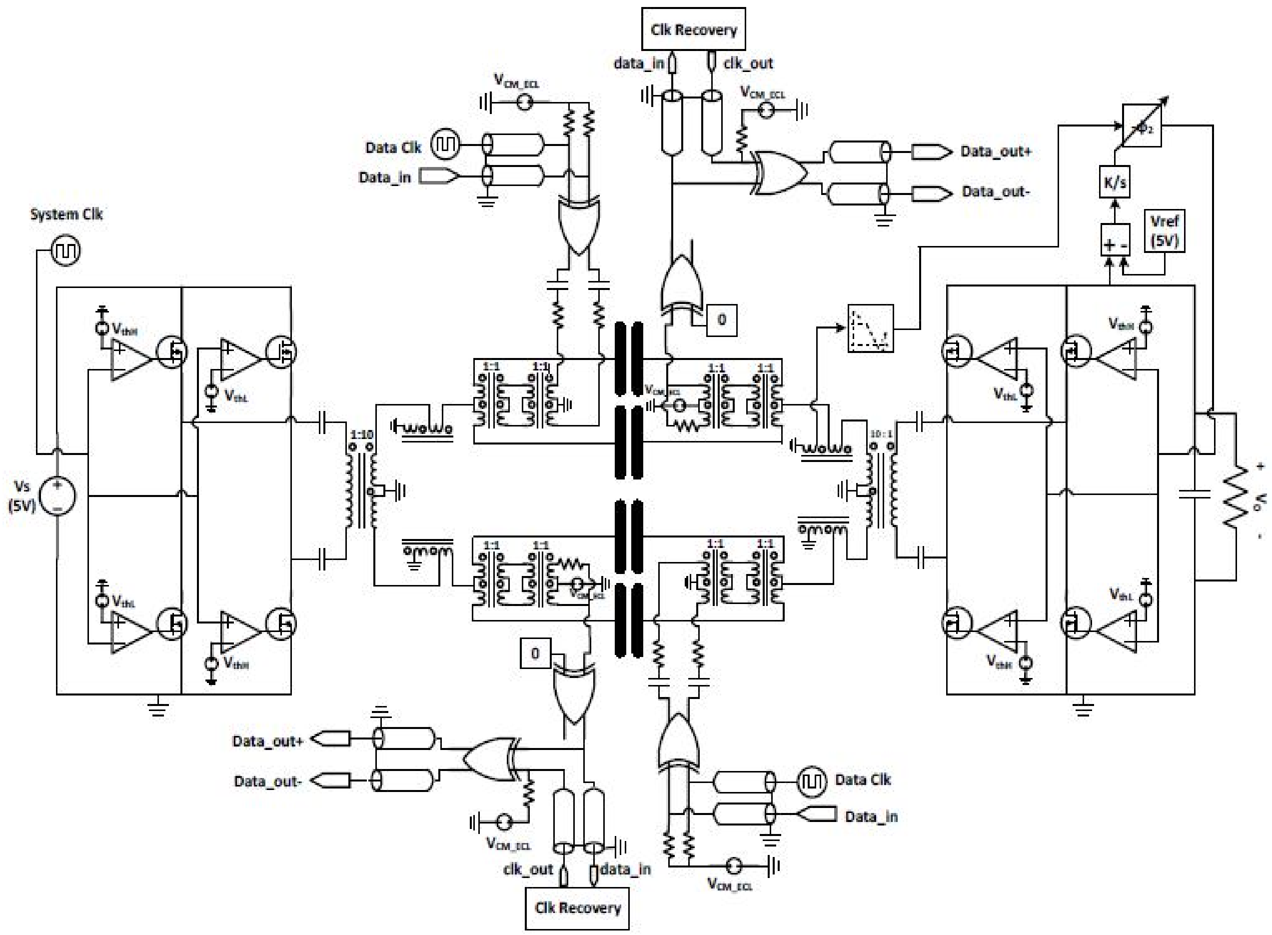

Figure 8: Detailed Capacitive Power and Data Transfer

C. FUNCTIONAL REPRESENTATION OF THE POWER TRANSFER

A functional representation of the power transfer is illustrated in Fig. 9. Primary side H-bridge supply voltage is replaced by MVS and the secondary side load voltage is replaced by MV_O, due to (1 : 10) transformers. R_T is the equivalent series resistance in one half of the RLC tank. The total inductance in the tank is 2L which is a summation of both the leakage inductance in the two (1 : 10) power transformers and the independent inductors used for current sense. The inductance L/2 is evenly distributed to make the functional diagram symmetrical allowing for simple analysis. The phase difference between the system clock and the tank current is denoted Φ_1 and the phase difference between the output ac voltage and the tank current is denoted $-\Phi_2$.

A phasor plot of MVs(t), MVo(t) and Ic(t) is illustrated in Fig. 10 to capture the steady state solution to the SRC system. It contains phasors 4/ MVs e+jΦ_1, 4/ MVo e+jΦ_2 and IA, assuming an operating point with negligible series drops and a current phasor as a reference with its phase equal to 0. Notice that under the ideal case when R_T = 0, the tank current is perpendicular to, and lagging the tank voltage.

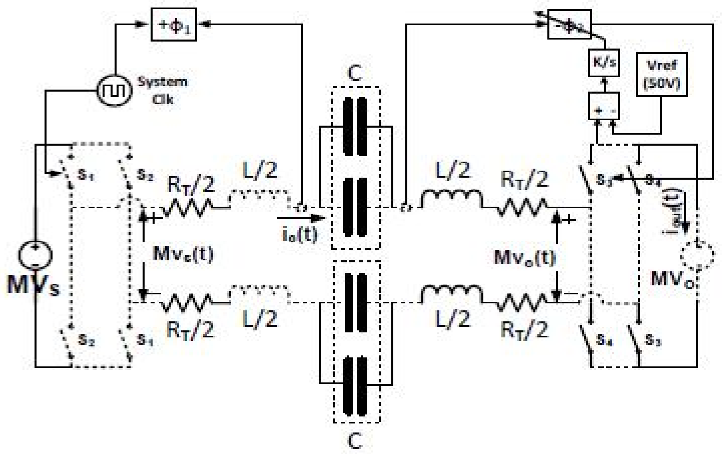

Figure 9: Series Resonant Converter with Phase Feedback

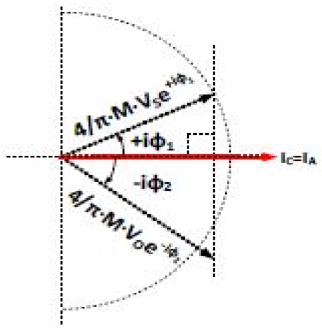

Figure 10: Series Resonant Converter with Phase Feedback

D. CAPACITIVE DATA COMMUNICATION ANALYSIS

In this section, we discuss and analyze capacitive data communication through the power channel. The data communication circuitry is illustrated in Fig. 11. This circuitry is repeated again for the bottom half allowing data communication in the reverse direction. Data bits are streamed at 100Mb/s and then XORed with a 100MHz clock. This is done to implement manchester coding. The data transformer shown in Fig. 20 has two center tapped (1:1) transformers in series. Two transformers are used instead of one because one transformer is not adequent to reject the common mode voltage interference. One center tap is connected to a resonant inductor and the other center tap is connected to the digital ground. Manchester coding is necessary because the data transformer does not transmit DC voltage. Manchester coding effectly shifts the center of the data spectrum to 100MHz. On the receiver side, two (1:1) data transformers in are series connected in a similar fashion. One center tap is connected to a resonant inductor and the other tap is connected to the midrail of the XOR logic circuit. The transmitted voltage is sensed and buffered by a logic gate, implemented with a spare XOR gate. The clock recovery circuit extracts the 100MHz clock on the manchester coded data. Then both the manchester data and the extracted clock are XORed again to recover the original data.

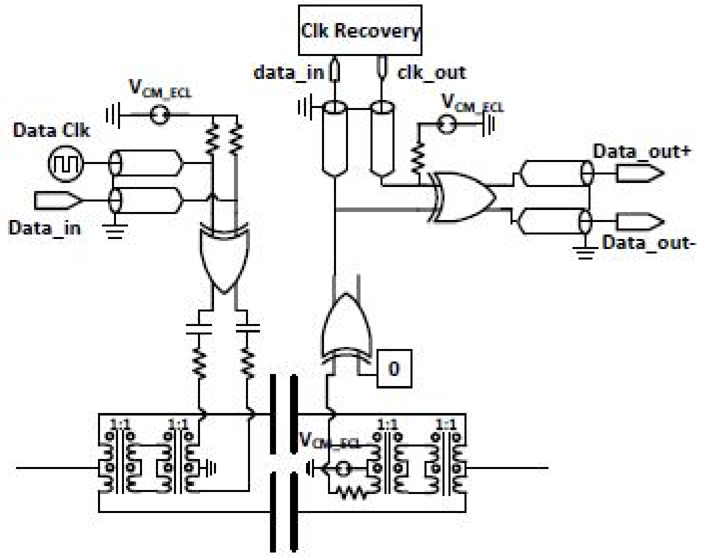

Figure 11: Data Communication Circuitry

IV. CONCLUSION

A inductive power transfer gives less efficiency because power is wasted due to magnetic fields. A capacitive power and data transfer circuitry that delivers both power and data on the same channel. A prototype was designed and built to illustrate functionality. This prototype can interface with USB terminal with both the supply voltage and the output voltage being 5V. It transfers 1.25W of power and has a power efficiency of 53%. Furthermore, a bidirectional data rate of 100Mb/s was illustrated. By building the circuitry on chip and allowing for equalization techniques, one can conceivably achieve higher efficiency with even higher data rate. This extends the wireless charging technology by incorporating data into the power channel.

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