Wireless power transfer techniques

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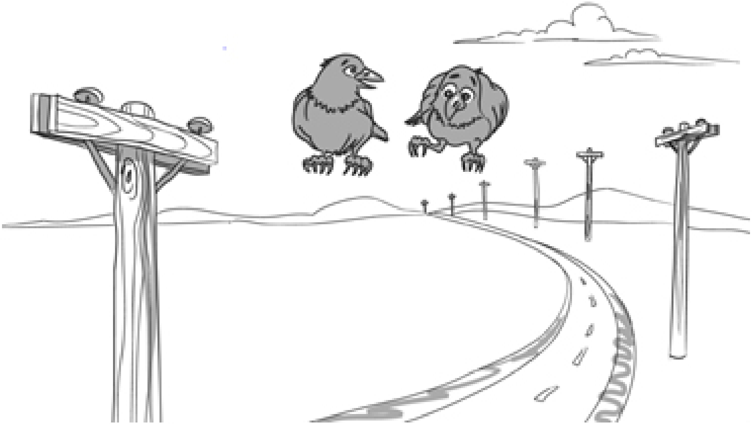
May 29, 2019

Wired vs Wireless



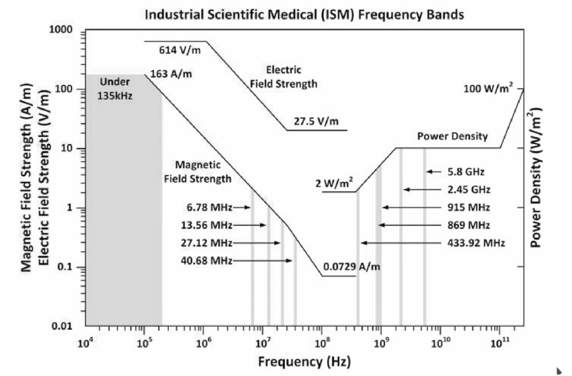
"TELL ME AGAIN THE BENEFITS OF WIRELESS."

Applications

- Implantable medical devices (IMDs)–uW
- Radio frequency identificaiton–mW
- Contact less memory–mW
- Wireless chargers–W
- Wearable devices–W
- Wafer level testing–W
- Electric vehicles–kW

Radiation Exposure

- X-rays/Gamma Rays
- RF/Microwaves
- Basic restrictions



- Human tissue specific absorption rate (SAR)

Modes of transfer

- Near field ($\lambda << d$)
- Far field ($\lambda >> d$)

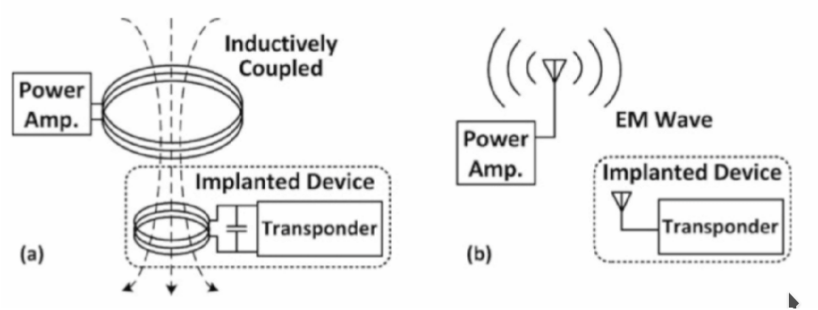


Figure: (a) Near field WPT (b) Far field WPT

Modes of transfer (contd.)

- Path loss for two isotopic transmit/receive antennas $A_{PATH} = -20log(\frac{4\pi d}{\lambda})$
- Resonance frequency: $F_{res} = \frac{1}{2\pi\sqrt{LC}}$
- ISM bands(13.56 MHz; 6.78 MHz/100–200 KHz)

[1] Depending on the coupling coefficient (k) and distance (d)

- Tightly coupled or inductive systems (d < 4cm as per Qi standard[2])
- Loosely coupled or resonant system (Spatial freedom, Multiple devices)

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[1] Wireless Charging: Inside the technology

[2] Another standard is AirFuel Alliance

Wireless charging standards

- Qi/AirFuel: 5W (mobile) / 15W (laptop)

Standard	Qi	Airfuel
Frequency	87–205 KHz	6.78±15KHz
Coils	Multiple	One
Data Communication	Load modulation	Bluetooth

Table: Comparison of standards[3]

Design Challenge: Signal+Power processing; transmission frequency, process technology, resonator toplogy, output regulation etc.

[3] Alternatively, a long range WPT using 2.45 GHz or 5.8 GHz can also be used.

Generic inductively coupled WPT

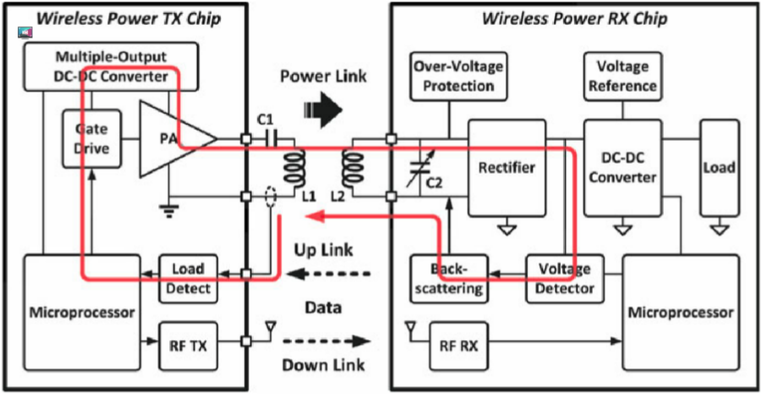
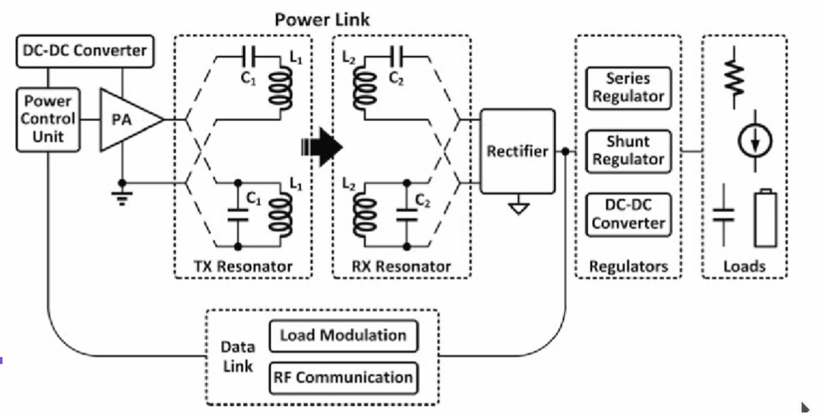


Figure: Block diagram of WPT with TX chip capable of powering up RX chip while enabling wireless communicaiton

WPT system

- Power amplifier
- Resonating Coils
- Rectifiers(AC $\rightarrow$ DC)
- Regulators

$$\eta_{TOTAL} = \eta_{DC-DC} \times \eta_{PA} \times \eta_{LINK} \times \eta_{RECT} \times \eta_{REG}$$



Power control stratgies-PA

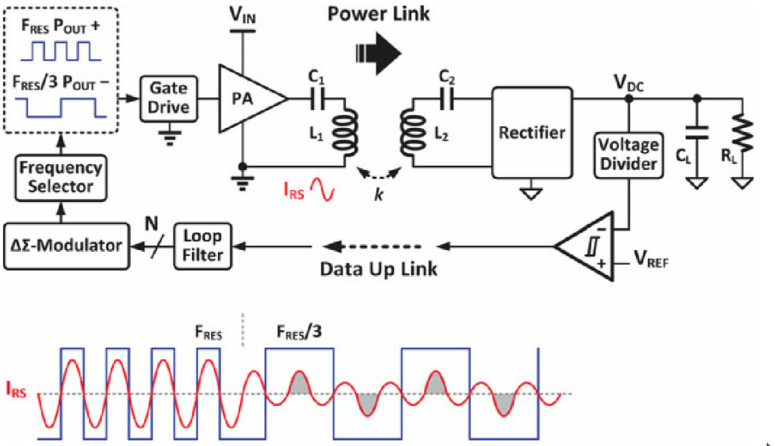


Figure: Transmission frequency hopping[4]

[4] Shinoda R, Tomita K, Hasegawa Y, Ishikuro H (2012) Voltage-boosting wireless power delivery system with fast load tracker by $\triangle \sum$ -modulated sub-harmonic resonant switching. In: IEEE international solid-state circuits conference digest of technical papers (ISSCC), 2012, pp 288â 290

Power control stratgies-PA

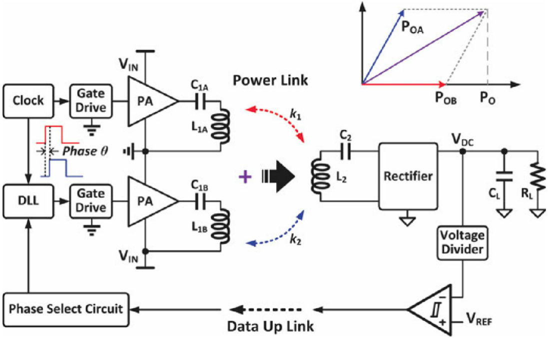


Figure: DLL based power control approach[5]

$$P_o = P_{PA} \times (1 + cos\theta)$$

[5] K. Tomita, R. Shinoda, T. Kuroda and H. Ishikuro, "1-W 3.3–16.3 V Boosting Wireless Power Transfer Circuits With Vector Summing Power Controller," in IEEE Journal of Solid-State Circuits, vol. 47, no. 11, pp. 2576-2585, Nov. 2012. doi: 10.1109JSSC.2012.2211698

Power control stratgies-Rectifier

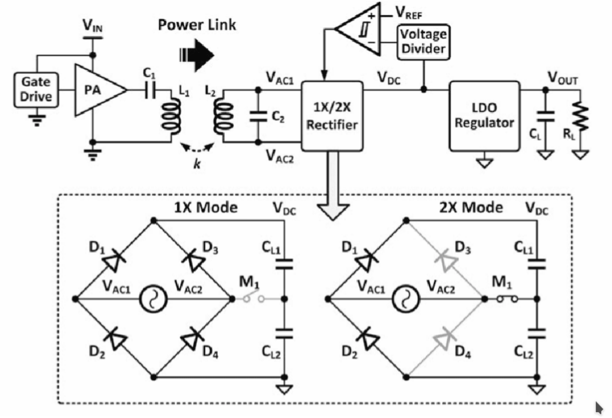


Figure: Reconfigurable rectifier[6]

[6] Lee H-M, Ghovanloo M (2012) An adaptive reconfigurable active voltage doubler/rectifier for extended-range inductive power transmission. IEEE Transac Circuits Syst II Express Briefs 59:481â 485. doi:10.1109TCSII.2012.2204840

Power control stratgies-Rectifier

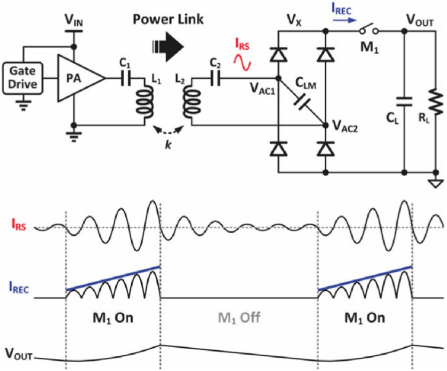


Figure: Pulse width modulation regulating rectifier[7]

$$P_{Cond.loss} = \frac{1}{NT}\int_{t_o}^{t_o+NT} I_{REC}^2 . R_{ON} dt$$

[7] Li X, Tsui C-Y, Ki W-H (2015) A 13.56 MHz wireless power transfer system with reconfigurable resonant regulating rectifier and wireless power control for implantable medical devices. IEEE J Solid State Circuits 50:978a 989. doi:10.1109/JSSC.2014.2387832

Power control stratgies-Rectifier

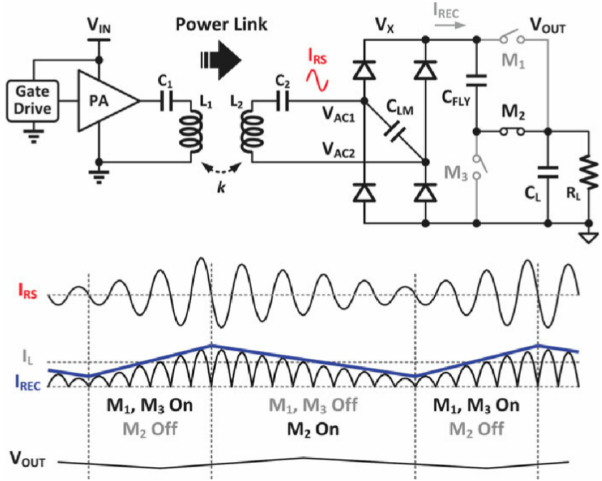


Figure: Pulse width modulation regulating rectifier[8]

[8] Li X, Tsui C-Y, Ki W-H (2015) A 13.56 MHz wireless power transfer system with reconfigurable resonant regulating rectifier and wireless power control for implantable medical devices. IEEE J Solid State Circuits 50:978â 989. doi:10.1109/JSSC.2014.2387832

Power control stratgies-Rectifier

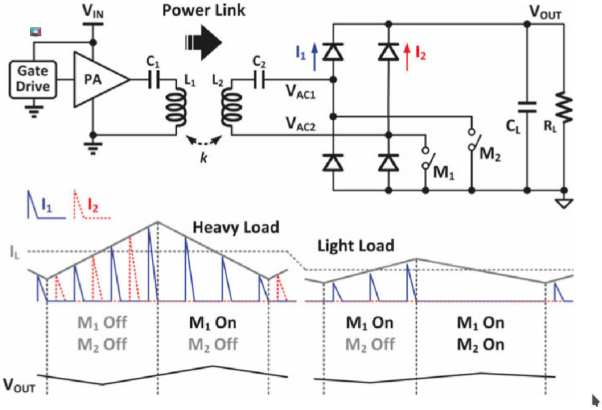


Figure: Pulse width modulation regulating rectifier[9]

[9] Cheng L, Ki W-H, Wong Y-T, Yim T-S, Tsui C-Y (2016) A 6.78MHz 6W wireless power receiver with a 3-Level $1X/\frac{1}{2}X/0X$ reconfigurable resonant regulating rectifier. In: 2016 IEEE international solid-state circuits conference (ISSCC), pp 376â 377

Power control stratgies-Rectifier

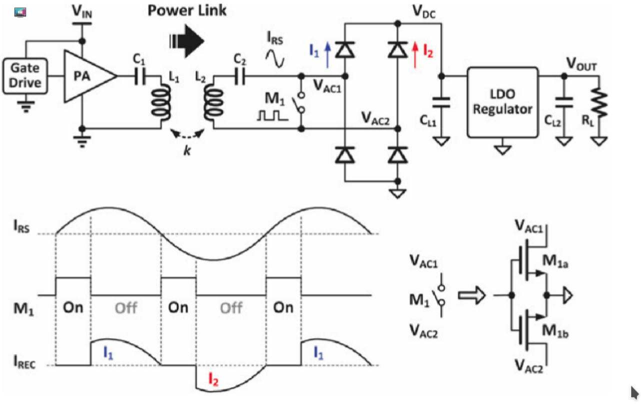


Figure: Pre-rectifier regulation[10]

- Zero-current switching

[10] Kiani M, Lee B, Yeon P, Ghovanloo M (2015) A Q-modulation technique for efficient inductive power transmission. IEEE J Solid State Circuits 50:2839â 2848. doi:10.1109/JSSC. 2015.2453201

Power control stratgies-Rectifier

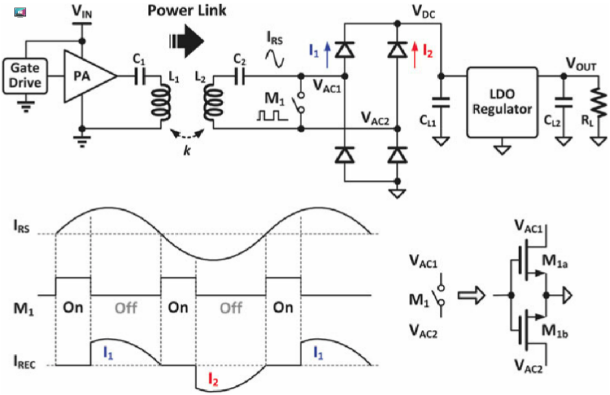


Figure: Pre-rectifier regulation[11]

- $R_{L,EQ} = R_L(8/\pi^2)(1-D)^2$

[11] Kiani M, Lee B, Yeon P, Ghovanloo M (2015) A Q-modulation technique for efficient inductive power transmission. IEEE J Solid State Circuits 50:2839â 2848. doi:10.1109/JSSC. 2015.2453201

Power control stratgies-Multilevel Rectifier

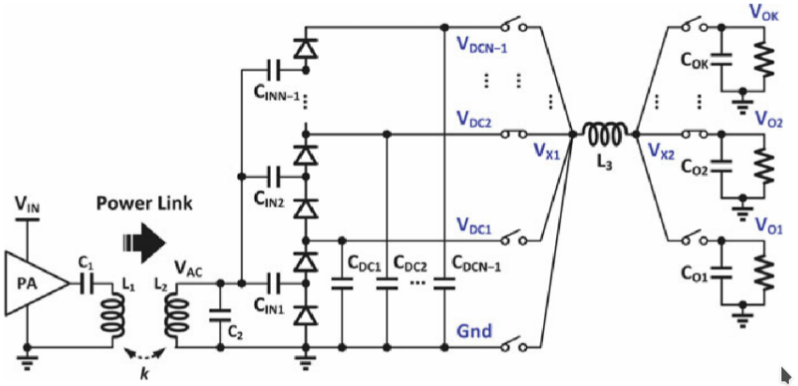


Figure: Single inductor multiple output operation (SIMO)

Power control stratgies-SIMO

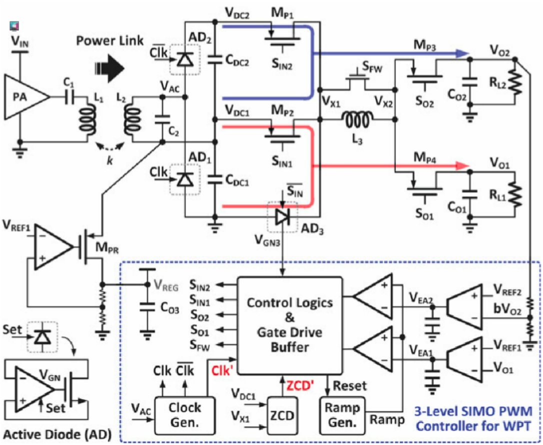


Figure: A 2X rectifier and 3-level SIMO converter

Power control stratgies-SIMO

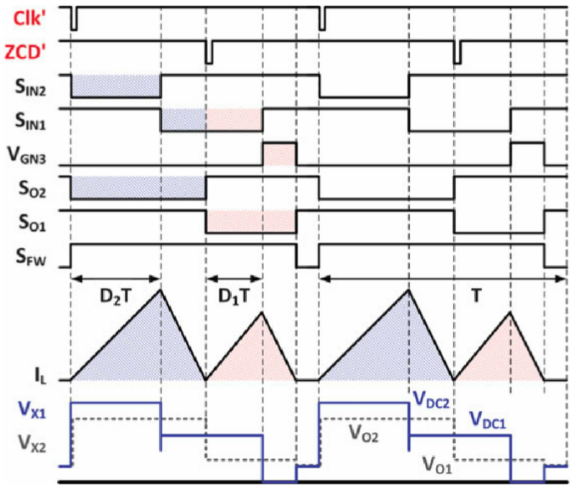


Figure: A 2X rectifier and 3-level SIMO converter

Coupled Coils

Coupled coil–Transformer model

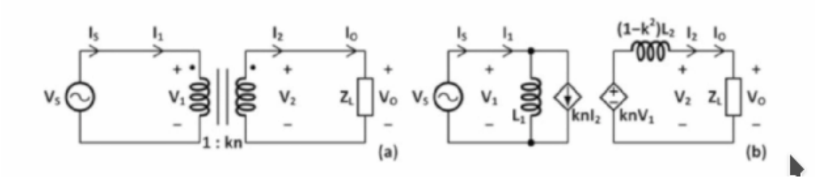


Figure: Transformer model of coupled coils

Mutual coupling$= M$
Coupling factor$= k = M/\sqrt{L_1 L_2}$
Turn-ratio$= n = \sqrt{L_1/L_2}$

$$V_2(s) = \frac{M}{L_1}(sL_1 I_1 - sMI_2) - sL_2 I_2 + s\frac{M^2}{L_1 L_2}L_2 I_2$$

Coupled coil–Reflected Impedance model

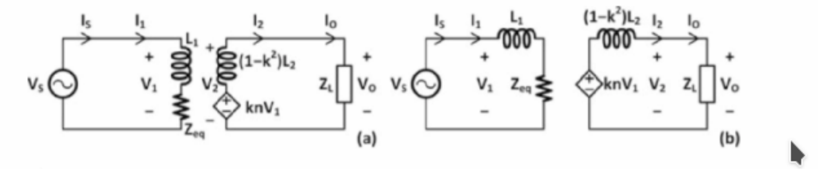


Figure: Reflected impedance model

Mutual coupling$= M$
Coupling factor$= k = M/\sqrt{L_1 L_2}$
Turn-ratio$= n = \sqrt{L_1/L_2}$

$$Z_{eq}(s) = \frac{M^2\omega^2}{sL_2 + Z_L(s)}$$

Coupled coil–Link Efficiency

- Link voltage gain$= \frac{V_o}{V_s}$
- Link efficiency$= \eta = \frac{P_o}{P_s}$
- Parasitic model (Section 3.2-3.3)

Coupled coil

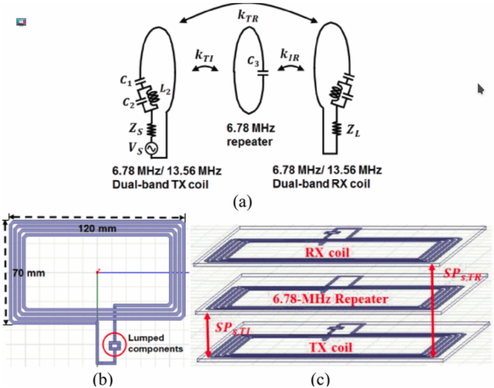


Figure: coil sizes[12]

[12] M. Kung and K. Lin, "A 6.78 MHz and 13.56 MHz dual-band coil module with a repeater for wireless power transfer systems," 2016 IEEE International Symposium on Antennas and Propagation (APSURSI), Fajardo, 2016, pp. 157-158. doi: 10.1109/APS.2016.7695787

Integrated coils

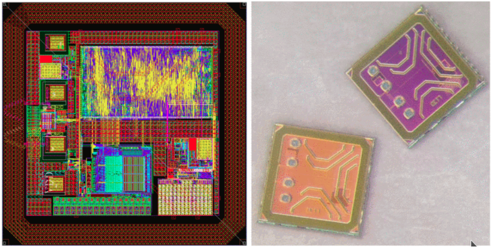


Figure: Integrated coils : Area < $1mm^2$

13

[13] W. Pachler, W. BÃ¶sch, G. Holweg and G. Hofer, "A novel booster antenna design coupled to a one square millimeter coil-on-chip RFID tag enabling new medical applications," 2013 European Microwave Conference, Nuremberg, 2013, pp. 1003-1006. doi: 10.23919/EuMC.2013.6686829

Summary

- WPT system/modes
- System level optimization
- Rectifiers
- Coils

- References: Images from Google repository and IEEE.
- Book:CMOS Integrated Circuit Design for Wireless Power Transfer Yan Lu and Wing-Hung Ki

Homework

Draw the transistor level diagram of a Full bridge rectifier.

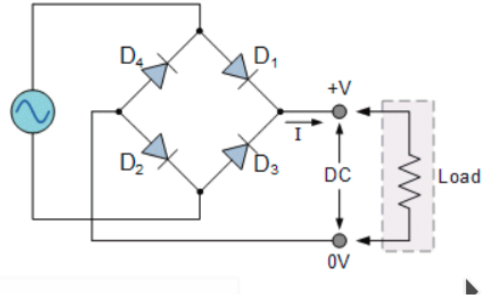


Figure: Replace diodes with transistors