A Multi-frequency WIPT System with a Stable Communication Carrier

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Abstract –**This paper proposes a new wireless information and power transfer (WIPT) system based on frequency splitting phenomenon. Three resonant frequencies appear in a four coils WPT system within certain distance under specific circuit parameters. Noticeably, the middle resonant frequency remains constant regardless of coupling coefficient change. This advantage provides a stable carrier frequency for communication to improve performance. In the proposed system, the highest and lowest resonant frequency are taken as power carriers while the middle is assigned to carry information. The simulation results show that the new system displays desirable communication stability with the OOK modulation (500kbps) and higher power efficiency (78.33%) than previous work due to overcoupling.**

Index Terms **—Wireless information and power transfer, frequency splitting, overcoupling, communication performance.**

1. Introduction

In recent years, wireless power transfer based on electromagnetic resonance has become a research hotspot in related fields. In 2007, an MIT research group developed a four coils WPT system[1]. In some applications, to control and indentify the devices in the WPT system, the chargers require information interaction with the devices. Hence, transferring information with power is significative on application. Asami evaluates the communication performance of a multi-hop M-ASK WIPT system[2]. However, the modem consumes a significant amounts of extra energy as it has to work constantly regardless of whether communication is neccessary. To overcome this weakness, Barmada presented a feasibility study on WIPT system, which transfer power and information at 2 different frequency bands[3]-[4]. Nevertheless, the system communication performance deteriorates rapidly when the distance of the transmit and receive coils changes, because the coils resonant frequencies vary with the coupling coefficient. To resolve this issue, a WIPT system with a stable resonant frequency to carry information has been designed in this paper. The circuit components are chosen carefully to achieve 3 resonant frequencies, the middle of which is independent of distance. In the system, the highest and lowest resonant frequency carry the power while the middle carrys the information. The simulations shows that the proposed system decline the error rate (500kbps with the OOK modulation) significantly over [4].

2. System analysis and design

The four coils wireless power transfer system can be represented in terms of lumped circuit elements. Fig. 1 shows the equivalent circuit of a four coils WPT system.

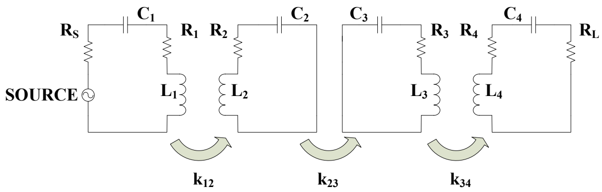

Fig. 1. Lumped equivalent circuit of a WPT system.

Circuit theory and Couple Mode theory (CMT) can be used to obtain the transfer function of the above circuit as (1) (Z_i represents impedance of the *i*th coil). From (1), it can be indicated that the transfer function may contain at most 4 peaks. A multi-frequency WIPT system requires more than one resonant frequency to transfer information and power respectively, but all the resonant frequencies of 2 or 4 peaks systems don't stay stable when the distance of coils changes. However, the proposed system with 3 peaks can provides an invariable resonant frequency for communication. The system transfer function is calculated with the circuit parameters provided in Table I, and Fig. 2 shows the results as a function of frequency under different coupling coefficients.

TABLE I
Circuit Parameters

Parameter	Value
R_L	50Ω
L_1,L_2,L_3,L_4	20uH
C_1,C_2,C_3,C_4	12.5pf
R_1,R_2,R_3,R_4	1Ω
k_{12},k_{34}	0.10
k_{23}	0.30
f_1	8.87MHz
f_2	10 MHz
f_3	12.25 MHz

$$S_{21}=\frac{j2w^2k_{12}k_{23}k_{34}L_2L_3\sqrt{L_1L_4R_SR_L}}{Z_1Z_2Z_3Z_4+k_{12}^2L_1L_2Z_3Z_4w^2+k_{23}^2L_2L_3Z_1Z_4w^2+k_{34}^2L_3L_4Z_1Z_2w^2+k_{12}^2k_{34}^2L_1L_2L_3L_4w^4} \quad (1)$$

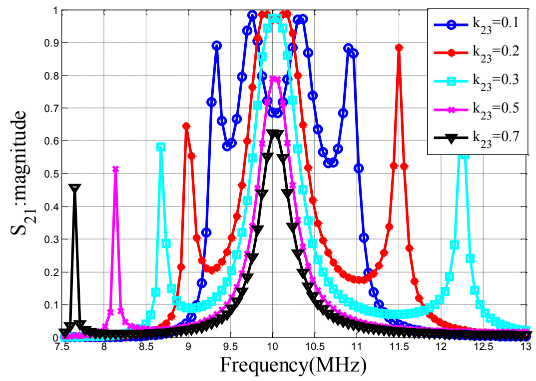

Fig. 2. S_{21} for different coupling coefficient.

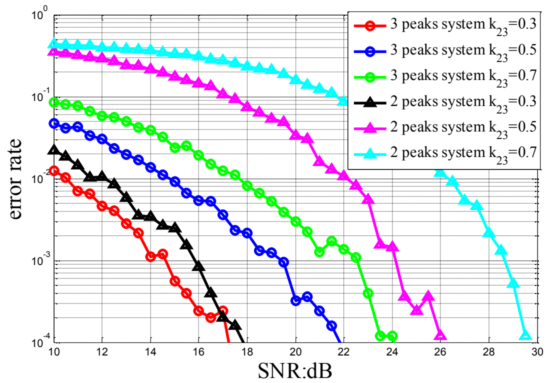

Fig. 4. Error rate for different SNR.

As it is shown in Fig. 2, three resonant frequencies appear when the coupling coefficient is larger than 0.2. Remarkably, the second resonant frequency remains stable when the coupling coefficient increases even further. Carrier frequency stability guarantees reliable communication. As a result, the middle frequency has the edge over the other frequencies as an information carrier. To achieve WIPT, the OOK modulated signals carried by the middle resonant frequency which is added with high power sinusoids (f_1 and f_2) are transmitted through the WPT channel. The system scheme is shown in Fig. 3.

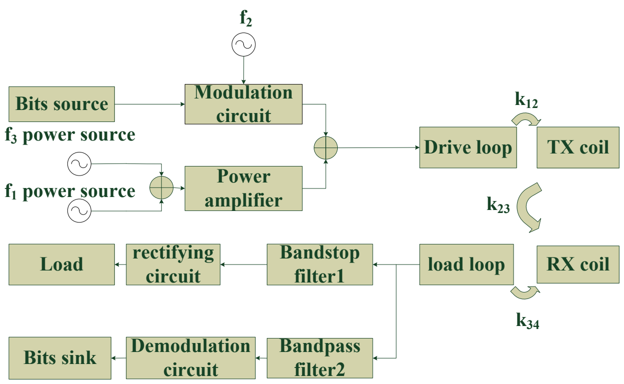

Fig. 3. Scheme of the proposed WIPT system.

3. Simulation and results

Power efficiency and bit error rate are two key parameters of a WIPT system. For this reason, these two parameters are focused on during the simulation.

The bit rate of the system is set to 500kbps. The modulated method is OOK and carrier frequency is f_2 (10MHz). In order to prevent the high power sinsiods from interfering with demodulation, the bandpass filter should heavily inhibit f_1 and f_3 (8.87 MHz and 12.25 MHz). In the simulation, out of band rejection of the filter is above 80dB. After demodulation, the error bit rate is calculated and compared with the method used in [4]. The result is displayed in Fig. 4. The line with triangles represents the error bit rate of the 2 peaks system, while the line with circles represents the error bit rate of the system proposed in this paper (3 peaks system). The error bit rate of the system don't vary violently with the coefficient k_{23}, which means that the system remains stable when the distance of the coils is altered. It's clear that the change of the coupling coefficient deteriorates the communication quality in 2 peaks system more significantly than that in 3 peaks system.

For impedance matching, the system energy efficiency that includes the power loss in the power source is

$$\eta = \frac{|I_4|^2 R_L}{|I_1|^2 (R_S + R_1) + |I_2|^2 R_2 + |I_3|^2 R_3 + |I_4|^2 (R_L + R_4)} \quad (2)$$

According to (2), the system efficiency is 78.33% which is much higher than that in [1] (40% only) due to the system working in the overcoupling regime. According to (1), greater coupling coefficient means that the energy exchanges between coils is more frequently, so more power is transmitted to the load rather than dissipating on the parasitic resistance in each period, which leads to high power efficiency.

4. Conclusion

A WIPT system based on 3 frequency bands is proposed. The system block diagram is validated through the simulation. The stability of the communication and power efficiency of the WIPT system is improved because of the unchanged resonance frequency and higher coupling coefficient.

References

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