

COMPACT DUAL-BAND WIRELESS POWER TRANSFER SYSTEM FOR BIOMEDICAL APPLICATIONS

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(生体医用向け小型化デュアルバンド無線電力伝送システムに関する研究)

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論 文 内 容 の 要 旨

Wireless power transfer (WPT) received a great attention in recent years due to its expendable potential to human daily life. This covers from convenient portable wireless charging, increase detectivity of life threatening defects; such as old sewage system, earth seismicity, improves traffic flow and increase human lifespan. However, with the previous developed WPT, such as coils-based, the system is fundamentally big and bulky. This become worst as direct solution of ferrite core is proposed, attempting to increase coils coupling-factor. These problematic solutions are rooted by the fact entanglement of quality (Q) with coupling (K) factors in conventional WPT system. Thus, without a new profound theory of KQ-products, designing an efficient compact WPT system for biomedical application is practically impossible.

Motivated by this, wireless power transfer research began with a proposal of attaining KQ-products separately. On this, various shapes of defected ground structure (DGS) are found to possess a loose KQ-products entanglement, which brings the degree of freedom on optimizing KQ-products independently. This is truly a discovery of an old KQ-theory of WPT system itself. With these merits, DGS resonators once again is proposed to maximized Figure of Merit (FoM), a universal scale of comparing various state of arts from our own. This is important because prior to these independent KQ-products, the maximum-recorded FoM is 0.86, and makes designers wonder if more efficient WPT system could be design based on DGS resonators and be applied to biomedical. Dispatched from this theory, dual-band wireless power transfer is proposed utilizing DGS resonators. Its performance surpassed poor coupled coils WPT system, by development of internal and external coupling theory. However, although the results are shown to be better, area increment may hinder the goal of biomedical application. On solving this problem, another proposal of minimizing WPT area is proposed by maintaining its original idea of previous system using series LC of DGS and lumped capacitors. After achieved goal of 50% compacted WPT system, another area saving integration method of completing dc conversion is proposed using cascaded WPT system and voltage-doubler. The same continues to apply with compact dual-band WPT system with application of dual-tone power to increase conversion at low input power of WPT system within biomedical safety.

Thus, to address the problems of WPT research for biomedical application, Chapter 2 begins with summary of the prior challenges of designing compact and efficient WPT systems. With superior development of defected ground structure (DGS) resonators as an improvement in WPT system, its better potential is yet to be discovered. Here, the profound Figure of Merit is again discussed, but based on maximum obtainable efficiency unlike before. Due to unfitting of previously established curve theory, rectangular defected ground structure is seen to have a better coupling per millimeter area compared to conventional DGS. As results, maximum figure of merit could be retrieve, surpassed previous published results of 0.86, by recorded figure

of Merit of 1.06 at 44 mm WPT distance using rectangular DGS.

On continuation of that, on Chapter 3, the importance of designing dual-band system is discussed for simultaneous data and signal transfer. By applying new proposed frequency dependent stubs of single fed line, an independent controllable resonance is achieved. The system employed cascade of external coupling of dual-band WPT system of circular DGS, which shows a better quality-factor about 250 and 350, respectively. Thus, using inter- and external coupling of frequency-dependent stubs and cascaded circular DGSs, both bands recorded 70% WPT efficiencies of S-parameter at 16 mm distance. This result is better in term of longer WPT distance than previous dual-band WPT system, which merely 30% power transfer capability at 7 mm distance.

As the trend of designing dual-band WPT system for biomedical application is undeniable necessary, compactness topic captures our attention. Thus, in Chapter 4, by using as an overlapped defected ground structures of series inductance and lumped capacitance, the proposed structure be able produce required KQ-products of wireless power transfer theory. With these KQ-products around 6.54 - 7.57, dual-band wireless power transfer is realized with WPT area half of previous proposed structure, which is around 50% compact. The circuit is yet maintained its inter- and external coupling within a limited WPT area as previous. This is in line with target of compact dual-band structure as currently less publications are focused on compact dual-band WPT system for biomedical applications. From the measurement validation, it showed power transfer capability is around 70% using 15 mm $\times$ 15 mm WPT size at 12 mm WPT distance.

Complementary of the proposed systems, an area saving integration method without using external circuit is presented to accommodate conversion power from alternating frequency signal to direct current at the end of receiver terminal. The conversation of power is carried out by a simple voltage-doubler. The integration of WPT system with voltage-doubler is done by cancelling the susceptance and matching the reactance of both output of receiver and input voltage-doubler. This is in favor because with the intended biomedical application, low frequencies distributed matching circuit will be impractical and lumped components will cause more losses. Thus, Chapter 5 is divided into two sections. In first section, the basic integration proposal using susceptance and reactance is presented with cascaded DGS dual-band WPT system. By measurement results, it shows the 35% and 40% of converted power is collectable at the load with separation of 20 mm, and with the presence of biological tissues, a slight decrease 1.27% and 1.6% of converted power is recorded using 25 mm $\times$ 50 mm WPT size.

In second section of Chapter 5, the integration of susceptance and reactance is once again being applied but using compact dual-band WPT system, which is proposed in Chapter 3. However, as we learn deeper, it is agreeable dual-tone of power, which passed thru dual-band WPT system is potentially, converts a higher efficiency at low input power. This technique targets 5%-10% of improvement compared to single-band power due to higher average of sinusoidal mixed voltage amplitude could be inject into the diodes. By applications of compact dual-band WPT system which bring a merit in term of biomedical application, dual-tone thru dual-band WPT system provides a safer power transfer capability in general, abides by IEEE safety regulations.