Trilogy of Wireless Power Transfer

WPT Systems

BASIC PRINCIPLES,
WPT SYSTEMS AND
APPLICATION

2 WPT Systems

Part 2: WPT Systems

Wireless Power Transfer System

Following the detailed explanation and description of the basic principles of wireless power transfer in Part 1, which are important, the wireless power transfer system will be described here.

First an overview of the wireless power transfer system and then detailed overview of different amplifier topologies will be given. Following the optimal selection of the amplifier, the correct selection of the possible coil combination must be made. In this chapter, tools and practical hints for higher and lower working frequencies will help to select the best fitting wireless power transfer coils. Not only the coils have an influence on the system efficiency, but also the correct selection of the FETs used at the amplifier stage. In the last chapter of this Part 2, all other components are mentioned which are also needed to realize a wireless power transfer system.

2.1 Wireless Power Transfer: An Overview

The general architecture of a wireless power transfer system comprises four basic building blocks, which are:

- An amplifier, also known as a power converter
- A transmitter coil that includes a tuning network
- A receiver coil that includes a tuning network
- A rectifier with high frequency filtering

Figure 2.1 shows a generalized block diagram of a wireless power transfer system highlighting the main building blocks and the coils. Each of the building blocks must be designed to work with the adjacent blocks, and as operating conditions vary, this can prove challenging. Therefore, each of the challenges will be identified and addressed with various solutions proposed. For simplicity we will refer to the amplifier through transmitter coil as “the source” and the receiver coil through output terminals as “a device.”

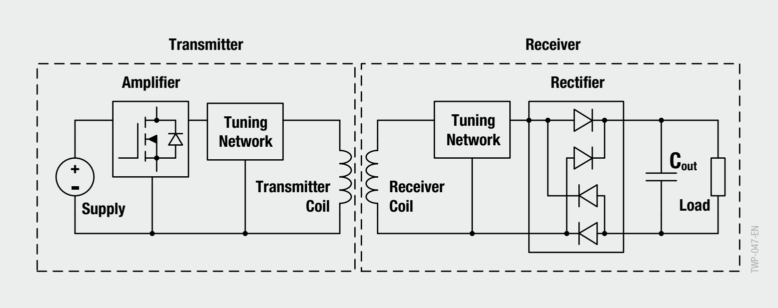

Fig. 2.1: Block diagram overview of a wireless power transfer system

The coils form the energy transfer mechanism regardless of the wireless power transfer technology employed, such as inductive or highly resonant. The choice determines

Low Frequency Systems

High Frequency Loosely Coupled Systems

how the coils are tuned and the choice of amplifier. Low frequency systems based on the inductive technology can simply rely on either a half-bridge or full-bridge power converter topology [25] and do not need tuning techniques to enhance the coupling between the coils because a magnetic core is used and the coils are spaced relatively close to each other. High frequency loosely coupled systems based on the highly resonant technology, on the other hand, require more specialized amplifier topologies to ensure lowest operating power loss, such as the ZVS class D and Class E [26] topologies and coil tuning to enhance the coupling between the coils.

A wireless power transfer system needs to function as a single converter, regardless of source to device pairing. The choice of coils, amplifier and rectifier topology result in variations of the interaction between each of these components, requiring a deep understanding of each block and how it interacts with the others. Variations in power demand and operating conditions affect the system and must be included in the analysis and design phases.

2.1.1 Wireless Power Transfer: Amplifier Topologies

Various amplifier topologies suitable for highly resonant wireless power transfer are presented in this section. Most traditional RF amplifier topologies are not suitable for wireless power transfer systems because their operating efficiency is too low. Only soft switching-based amplifier topologies will be considered. These amplifiers have the added benefit of a higher power to cost ratio that help keep system costs down.

2.1.2 Coil Network Simplification

It is helpful during amplifier design, evaluation, and topology comparison to simplify the entire coil circuit into an equivalent impedance (Z_{Load}). Accurate impedance values for all the components, at the operating frequency, are needed to yield an accurate simplified equivalent impedance that the amplifier drives. Figure 2.2 shows this concept applied to a single device loaded coil.

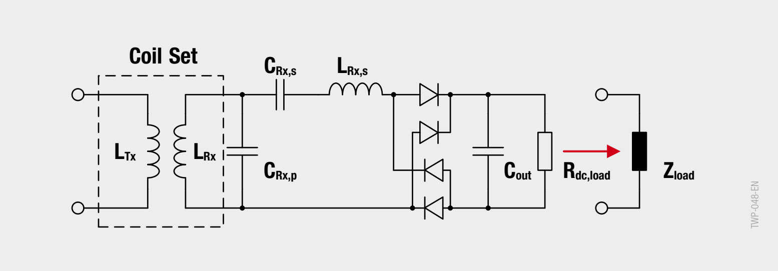

Fig. 2.2: Wireless power transfer circuit simplification

S-parameters are the best method for determining the impedances of each of the components in the circuit. These can be measured or in some cases are provided by the component manufacturer. Non-linear components, such as rectifiers, however pose a challenge in that they require complex signal measurement for accurate impedance measurement and fall outside the scope of this work.

Amplifier analysis presented in this work refers to Z_{Load} and implies the full circuit shown in figure 2.2 and is referred to as the reflected load impedance. Whenever R_{DCLoad} is discussed, then only the final dc load resistance is being described.

2.1.3 Amplifier Topologies suitable for Wireless Power Transfer

Popular amplifier topologies include the class E amplifier [27], with theoretical 100 % conversion efficiency and the collection of class D amplifiers such as the current-mode class D [28] and voltage mode class D [29] with the recent Zero Voltage Switching (ZVS) variant [30]. Some of these topologies can be configured differentially for high power capability. All the amplifiers presented here operate at a fixed frequency and at 50 % duty cycle due to ISM band restrictions.

Zero Voltage Switching (ZVS)

2.1.4 Class E Amplifier

The class E amplifier is the most popular amplifier topology for wireless power transfer due to its simplicity and high operating efficiency. The single-ended class E amplifier together with the ideal operating waveforms [31] is shown in figure 2.3.

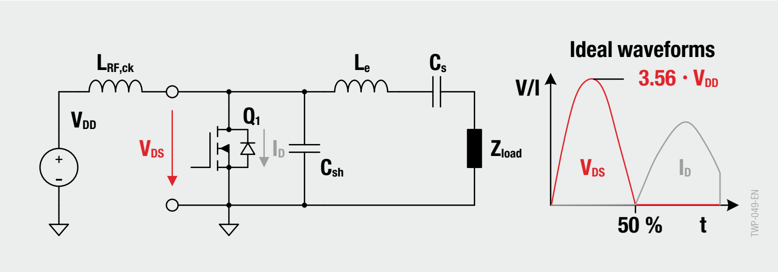

Fig. 2.3: Single-ended class E amplifier topology with ideal operating waveforms

The device voltage rating needs to exceed the supply voltage (V_{DD}) by a factor of at least 3.56 when operating under ideal conditions. However, the peak device voltage can be as high as 7 times the supply voltage due to load and coupling variations. Therefore, designers must consider all operating conditions when selecting a suitable device [31].

One of the main advantages of the class E topology is that it requires only a ground-referenced gate driver, regardless of whether it is configured single-ended or differentially. The LM5114 [32] or UCC27611 [33] from Texas Instruments are suitable for larger EPC eGaN® FETs and for differential mode configuration of the half-bridge gate driver IC, such as the LMG1205 [34] where the high-side drive is simply kept at ground potential, can be used. For low power designs, the EPC2037 [35] can be used for the amplifier which has a low enough input capacitance that the controller's digital output is sufficient to operate the transistor, thus saving the cost, space, and power losses associated with the driver.

The class E amplifier is susceptible to high losses when presented with a load impedance that deviates from the ideal, which is nearly always the case in wireless power