Abstract—Unique word (UW)-OFDM is a newly proposed multicarrier technique that has shown to outperform cyclic prefix (CP)-OFDM in fading channels. Until now, the spectrum of UW-OFDM is not thoroughly investigated. In this paper, we derive an analytical expression for the spectrum taking into account the DFT based implementation of the system. Simulations show that the proposed analytical results are very accurate. Compared to CP-OFDM, we show that UW-OFDM has much lower out-of-band (OOB) radiation, which makes it suitable for systems with strict spectral masks, as e.g. cognitive radios. Further, in this paper, we evaluate the effect of the redundant carrier placement on the spectrum.

I. INTRODUCTION

Multicarrier techniques, especially orthogonal frequency division multiplexing (OFDM), have been adopted as the main signaling schemes for most wireless communications standards due to their ability to counteract the effects of time dispersive channels, the simplicity they offer in terms of equalization, flexibility for achieving different data rates and having flexible spectral characteristics. OFDM is a block-wise transmission scheme in which a number of data symbols are modulated using an inverse discrete Fourier transform (IDFT). When a high data rate signal is passed through a time-dispersive channel, intersymbol interference (ISI) occurs. In OFDM, a time guard interval is inserted between the consecutive OFDM frames to compensate for the ISI. Different guard intervals can be found in the literature such as cyclic prefix (CP), zero padding (ZP) and known symbol padding (KSP) [1], [2] out of which CP is more utilized in practical systems. Recently, a new family of OFDM systems named UW-OFDM is proposed, in which the time guard interval is part of the IDFT block [3]. In a two-step implementation of UW-OFDM systems, first a block of zeros is constructed at the tail of the IDFT output. This can be done by two approaches [4]: 1) by appropriately loading a set of redundant carriers in systematic coded UW-OFDM system, i.e. data carriers and redundant carriers are separated, and 2) by distributing the redundancy over all active subcarriers by using a code generator matrix in non systematic coded UW-OFDM system. Then, in the second step, the zero part of the block is filled with the known unique word samples. Like CP, the added unique word transforms the linear convolution of the transmitted signal with the channel impulse response into a cyclic convolution. This allows for a low complexity equalization at the receiver. Contrary to the CP which is random, the unique word is deterministic and can be designed for some practical needs such as synchronization or channel estimation. Although the UW-OFDM frame is shorter than CP-OFDM and contains lower number of data symbols, the bit error rate and throughput of UW-OFDM is comparable to those of CP-OFDM [3], [4].

The spectral behavior is an important issue in multicarrier systems, as it is known that OFDM based systems have high sidelobes. As in practice, transmission schemes must meet some regulatory spectrum masks, it is of importance that the in-band and out-of-band radiation of the system is controlled. For CP-OFDM, much research has been devoted to this topic. However, most of the studies which require the spectral model have considered a model that is based on the analog implementation of the multicarrier systems, as e.g. for spectrum modeling [5], blind carrier tracking [6], in-band and out-of-band radiation reduction and sidelobe suppression [7], [8], [9], [10], [11]. Although this analytical model is easy to use, it is not precise for practical systems, in which multicarrier transmitters are typically implemented by an IDFT followed by a digital-to-analog converter, and the power spectral density of this implementation is generally not equivalent to that of the analog implementation. Conditions for equivalency of these approaches are discussed in [12]. The spectral characteristics of CP-OFDM based on the DFT based implementation is investigated in [1], [13], [14].

To our best knowledge, the spectrum for UW-OFDM is only considered in [4], where the authors claim that UW-OFDM has lower out-of-band radiation than CP-OFDM. These results were based on simulations only. In this paper, we derive the analytical expression for the power spectral density of systematic coded UW-OFDM system using the DFT based implementation. In order to obtain an expression for the spectrum of CP-OFDM systems, in [1], it is assumed that the symbols transmitted on the carriers are independent. This assumption is not applicable to UW-OFDM, where the redundant carrier symbols are a linear combination of the data symbols, introducing correlation between the subcarriers. Fortunately, this correlation is repeated in the successive UW-OFDM symbols. So, the sequence at the output of the UW-OFDM is cyclostationary. We use this property to derive novel expressions for the spectral behavior of UW-OFDM. With these expressions, we can thoroughly analyze the effect of the parameter choice on the in-band and out-of-band radiation, but they are also useful for other signal processing tasks such as those mentioned for CP-OFDM. Our simulation results show that the proposed expressions are accurate. With the