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Identification of Best Candidate Topology for Paralleling Standardised VHF DC-DC Power Converters

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Abstract—This paper describes the ongoing research towards identifying a best candidate topology of Very High Frequency power converter with the goal of paralleling standard cells. Such an association of similar elementary converters requires load independence. A benchmarking highlights a Class E2 resonant DC-DC converter. The paper details the selection and identify equipment needs for testing the candidate topology as well as a parallel association.

Index Terms—VHF, Converter, DC-DC, Paralleling, Class E

I. INTRODUCTION

Very high frequency Power conversion was first introduced in 1950 with the development of the first Class D switching mode power amplifier. Since then, many studies have been conducted toward implementation of Very High Frequency (VHF) power conversion concept to power converters. It is true that a drastic increase in switching frequency imply numerous advantages in terms of increased power density, use of air core inductors and integration of passive components [1]. This is because the amount of energy circulating through the passive components are of smaller amount. This allows for the use of smaller size passive components [2]. Nevertheless, increasing switching frequency implies impactful disadvantages such as high switching losses, core-losses and complex dead-time implementation. Back in time, when Nathan. O. Sokal introduced the first single switch class E power amplifier [3]. This was a breakthrough as this topology could support soft-switching characteristics also known as Zero-Voltage Switching (ZVS). Still at that time, semiconductor technologies were not adequate for high switching frequency as their parasitic components were too high and with too slow rise-time. But when GaN technology was commercialised in 2004 [4], this has renewed the interests in high frequency power conversion. Figure 1 shows the institutions which have contributed in VHF

power conversion during the past 10 years. The countries that are the most involved in VHF power conversion are Denmark, USA, China and Japan. The typical targeted applications by these work is mainly related to wireless power transfer (WPT)[5], LED Drivers[6], Plasma generation[7] and Power tracking system[8].



Fig. 1: WorldMap of VHF Actors during the past 10 years (2014-2024)

Power converters with switching frequency of 13.56MHz proposed in [9] and [10] was able to provide an output power of 2kW and 1kW respectively. Still few works have been done with regards to high power application of VHF Power converters. This is due to the fact that physical constraints, limited GaN/SiC MOSFETs voltage and current rating and gate drivers performance do not allow for high power application of VHF Power conversion. Therefore, the application range of VHF Power converters are limited to low power requirement ones. One strategy to bypass these limitations

could be operating VHF Power converters in parallel. Few works have been done with regards to paralleling VHF power converters [11], [12]. Until now, these research works which describe paralleling or interleaving VHF power converters have been done to explore questions such as testing control strategy performance, power balancing and feasibility of paralleling VHF power converters. Consequently, the main idea of building a network of VHF power converters that may address a wide range of applications has not yet been addressed.

II. RESEARCH OBJECTIVES AND CHALLENGES

A. Objectives

Standardisation in power converters bring up interesting opportunities to the table such as automated converter design [13], modular electronic design approach (Power Electronic Building Block or Power Converter Array), reduced heterogeneity and favor a more circular economy approach of power electronics system [14]. The objective behind this research work is to dissociate application needs and power converter performance by concealing the opportunities that standardisation of power converters propose with the one that VHF power conversion propose. In this way, the field of application of VHF Power conversion could be extended by paralleling high performance DC-DC VHF power conversion cell as higher power level could be achieved.

Thus the validity of this approach will have to be investigated based on gain in efficiency, power density, reduced heterogeneity, overall system cost and life cycle analysis. In this context, a thorough analysis of the literature review has allowed the creation of a database regrouping a vast majority of the topologies that have been used for VHF power converters since 1993 as shown in figure 2. Considering this database, the next and main objective is to identify which VHF topology best fits the criteria specific for paralleling converters.

B. Challenges

VHF Power conversion though it is an interesting approach for power electronics, implies many different challenges that are listed in table I. These challenges can be classified into 3 different groups namely components, adjacencies and architectures [1], [2]. As we increase switching frequency, parasitic elements such as output capacitance and on-resistance of transistors and ESL or ESR of passive components cannot be neglected anymore [15]. This is because at VHF band switching frequencies (30-300 MHz), the value of the passive components are of comparable size as those of the parasitic components. This limits the operating condition of a VHF Power converter as efficiency can be affected. It also limits how high the switching frequency can be as the value of the passive components cannot be lower than the value of the intrinsic parasitic components of the passive and active components. Another important limitation of the proposed approach is the fact that at very high frequencies, Electromagnetic interference (EMI) tends to be radiated emission rather than conducted emission [16]. As there will be multiple parallel converters, they are going to disturb one another.

TABLE I: Challenges of VHF Power Conversion

Components	Architectures	Adjacencies
Losses (Core losses, Skin and Proximity effect)	High peak current requirement to charge input capacitance of switch	Increased radiated EMI as frequency increases.
Integration of inductive components	Single operating point for resonant structure	Operating point dependent on temperature.
Creation of Galvanic isolation	Simple topology with few auxiliary blocks.	
Cross limit of switching component	Maintaining ZVS behaviour	
Non-linear behaviour consideration	Isolation implementation	

Consequently, suitable strategy and solutions will have to be implemented so as to limit how the cells are going to influence each other.

III. EVALUATION OF CONVERTER TOPOLOGIES

One main aspect which is not clear in VHF Power Conversion is the performance evaluation of the different topologies. Multiple research works similar to [5], [17] have tried to address this issue by comparing their work with similar ones based on the switching frequency, input/output voltage, output power, number of passive and active components, maximum achieved efficiency and power density. Still these comparisons is not enough to be able to conclude on the performance of the topologies as these works are comparing VHF Power converters that are not based on the same input specifications, technologies and targeted applications. Thus, in order to achieve a high performance DC-DC VHF Power conversion unit, the first step was to be able to define criteria that this cell shall respect so as to allow for paralleling of VHF power converters and standardisation. These mandatory criteria listed below will serve as filters to identify the best fit VHF topology for paralleling VHF power converters:

Criteria for the unit DC-DC VHF power converter cell:

- Load independent behaviour for both individual and network operation;
- Robustness against Component tolerance;
- Power balancing behaviour in a network.

Most resonant VHF power converters have only a single operation point where ZVS and ZDVS conditions are satisfied. The converter efficiency drops significantly when the operating conditions are not fulfilled. Since the publication of Nathan. O. Sokal [3], Zulinsky demonstrated in 1990 [18], that load independent behaviour could be achieved for a Class E power amplifier by giving up on ZDVS condition and maintaining only ZVS condition [19]. Since then, some articles have proposed variant of Class E2 DC-DC converter that support load-independence up to a certain limit [17], [20], [21]. Considering the diversity of VHF topologies presented in figure 2, the first step towards developing the unit standardized VHF conversion cell implies the selection of the best candidate topology that

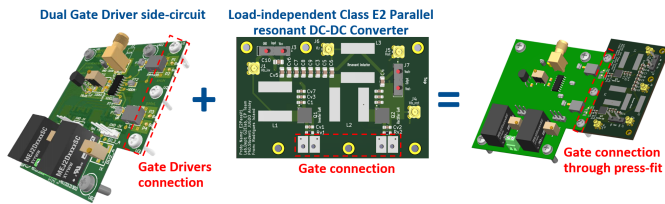


Fig. 5: Gate Driver SI8274 in press-fit contact with E2 parallel resonant DC-DC converter

switching VHF power converters. The presented Class E2 parallel resonant converter do comply with the criteria set but serves only as a case study for identifying problems and possible solutions with regards to paralleling VHF DC-DC power converters. Hence, the final VHF power conversion topology still needs to be identified. The applicability of the approach still needs to be proven. The main goal by the end of this research work would be to be able to conclude on possible gain in terms of cost, power density, efficiency, reduced heterogeneity and life cycle analysis. The literature review has confirmed the validity of the research question and this may bring another key towards implementation of standardised power electronic systems.

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