Review of very high frequency power converters and related technologies

***Abstract*—With the increasing demand of volume and efficiency, very high frequency (VHF) power converters (30–300 MHz) have attracted great attention. Based on the emerging power converter technology, the operating frequency has been pushed up to tens and hundreds of Megahertz. Under such high operating frequency condition, the value and volume of passive component can be greatly reduced and the power density can be improved. However, many concerns and challenges come along with the increasing operating frequency, such as high switching loss, high driving circuit loss, parasitic component effect. This paper reviews the state of the art technology related with VHF power converter, which starts from the various topologies of VHF converter, including its inverter stage, matching network stage and so on. Secondly, the different magnetic components and semiconductor devices have been evaluated under VHF condition. Finally, the high efficiency driving methods, such as resonant driving method and self-resonant driving method, have been demonstrated. From component to system, a guideline of VHF converter and related technologies has been illustrated in this paper.**

***Index Terms*—Very high frequency converter; magnetics, driving method.**

I. Introduction

In many power converter applications, great demands have been put forwards for small volume, easy manufacturability and better performance. To address above concerns, a fundamental method is to push up the operating frequency. Under high operating frequency condition, the energy stored in passive components during every period can be greatly reduced. Thus, the value and volume of passive components can shrink, in order to achieve higher power density based on miniaturization and integration. However, there are many challenges that need to be solved in tens and hundreds of MHz. Advanced topologies and driving strategies should be developed to reduce the switching loss and driving circuit loss, which play important roles in system total loss. Meanwhile, there are also great requirements for the magnetic components and semiconductor devices that suitable to operate in VHF condition.

The RF power amplifier technology provide another perspective for VHF power converter. Usually the RF amplifier deals with small power transformation while power converter needs to transfer larger power. Based on the similarity, some amplifier architectures have been applied in VHF converters [1-8]. In RF condition, amplifier transforms DC components into high frequency AC components. In Switching Mode Power Supplies (SMPS) VHF converters, this transformation is still needed, no matter in DC/AC converters or DC/DC converters. According to duality principle, the rectifier stage, regulating high frequency AC component to DC component can be derived based the inverter stage. With the combination of various inverter stage and rectifier stage, different VHF power converter have been proposed [9-64]. The properties of these converters are greatly improved, including high power density, low profile and fast dynamic response.

Usually, the efficiency is a major limitation of system operating frequency. Because the switching loss almost forms a proportional relationship with the switching frequency. Thus, soft-switching characteristics are expected in VHF converters. In aforementioned VHF converters, zero voltage switching (ZVS) technology is always applied to reduce to the turn-on loss of switch. Meanwhile, the diode in the rectifier stage is also expected to operate in soft-switching condition. Both the soft-switching characteristics are achieved by resonating between resonant inductor and capacitor. It should be mentioned that in VHF condition, the value of passive resonant component is quite small, thus, the parasitic capacitive and inductive component caused by semiconductor devices and layout should be carefully taken into consideration. Meanwhile, many topologies have fully adopted these parasitic components.

For VHF converters, great attentions should be paid on the utilization of parasitic parameters [29-36], the derivation of the topologies [37-42], properties of semiconductor devices [21-28], and the design of passive components [43-49]. Another challenge for VHF converter is magnetic component, which leads a large part of system total loss. Usually the volume of inductor with magnetic core decreases under high operating frequency. However, considering core loss and temperature limitation, the volume cannot follow ideal trend. In small value condition, air core magnetic component is widely adopted, which can avoid the core loss. Many research has been done to optimize the winding structure in order to improve system efficiency.

Besides the topology and component perspectives, in VHF condition, the system efficiency also suffers a lot from driving loss. In square waveform driving method, by charging and discharging input capacitor, the switch turns on and turns off during every cycle. However, the loss of switch input capacitors is total dissipated. Thus, the driving loss keeps increasing with the increment of operating frequency, especially at tens of MHz. Advanced driving methods, such as resonant driving method and self-resonant driving method are proposed to address the problem.

In this paper, the VHF converters are analyzed from several perspectives, such as topology, component and driving method. In Section II, different inverter stages, rectifier stages and matching networks are analyzed. Meanwhile, the non-isolated and isolated converters are introduced. The magnetic component and semiconductor device characteristics are illustrated in Section III. The relationship between corresponding loss, volume and frequency are analyzed. In Section IV, the advanced high efficiency driving methods are demonstrated in VHF condition. Section V concludes this paper.

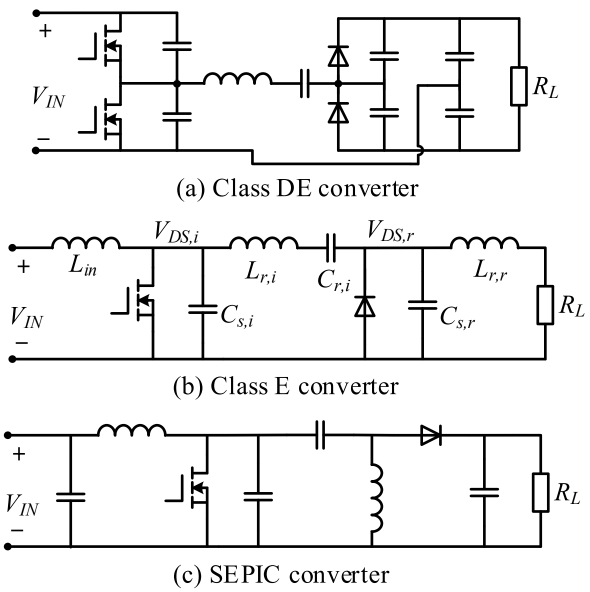


Fig. 1 Very high frequency resonant power converters.

II. Topology Analysis of VHF Converter

A. Non-isolated DC/DC Topology

The resonant power converters with soft-switching characteristics are greatly expected in very high frequency operation. According to current research, three topologies are mainly adopted in the VHF situation, namely the class DE [65]–[67], SEPIC [68]–[70], and class E converter [71], [72], as shown in Fig. 2 respectively. These topologies can be divided into inverter stage and rectifier stage which achieves DC-to-AC transformation and AC-to-DC transformation respectively. The inverter stage and rectifier based on the class DE and class E can be assembled according to different situations. For the class DE converter, there is only one resonant inductor adopted in the circuit which helps to reduce the system volume. However, it can be seen that there are one low side switch and one high side switch in the inverter stage. For the integration manufacture, some advanced processes, such as triple well or Silicon on Insulator (SOI) should be adopted. Meanwhile, great attention should be paid to the parasitic components in the half-bridge structure, which significantly affect the operation of the very high frequency converters.

As the figure shown, only one low side ground referenced switch is needed in the SEPIC converter. It also can be seen that there is one high side diode in the rectifier stage. Schottky diodes with Si and SiC material are widely adopted in very high frequency converters due to the low forward voltage drop and fast switching speeds. However, in very high frequency situations, the forward recovery voltage greatly affects the characteristics converters. Within very short transition time, the forward voltage can be increased by 50 %, causing unexpected loss and reducing system efficiency [73]. In high output voltage, the forward voltage drop plays a small role, however, in low output voltage condition, the conduction loss can not be ignored. Meanwhile for hundreds of MHz operating frequency, diodes with CMOS design methods are rarely available. At very high frequencies, the conductivity modulation of power diodes cause an inconvenient loss, which has been analyzed in [74], [75]. Thus, the diode in the rectifier stage is expected to be low side one which can be replaced by a switch with simpler driving circuit.

The class E converter as shown in fig. 2b is the most widely adopted architecture among DC-DC VHF converters. It can be seen that with one low side switch in inverter stage and one low side diode in rectifier stage, the topology is very suitable to operate in VHF condition and easy to be integrated. As mentioned above, in the rectifier stage, a synchronous transistor can be adopted to replace the diode. Also, the output parasitic capacitance of switch and diode can be absorbed by the corresponding resonant capacitors. In even higher frequency situations, the output capacitance is large enough and no more discrete resonant capacitors are needed. However, it should be mentioned that the values of output capacitance of switches and diodes are not in a constant level, which usually forms a non-linear relationship with the voltage. Thus, the non-linear characteristics should be taken into consideration during design procedure. Also, the capacitance across the switch should be firstly decided, which cannot be larger than the parasitic value. Based on the capacitance, the corresponding resonant inductor can be decided at aiming operating frequency.

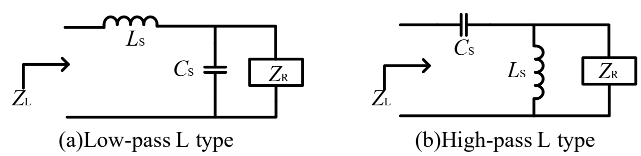


Fig. 2. The diagrams of different non-isolated matching networks.

Sometimes, the matching networks are added between the inverter stage and rectifier stage to adjust the equivalent impedance of rectifier stage. Fig. 2 shows the typical matching networks consisted of inductors and capacitors. Based on frequency domain characteristics, they can be divided into low-pass type and high-pass type. The low-pass one can eliminate the effect of high harmonics. However, from the perspective of energy adoption, besides fundamental waveform, high-pass one can also take advantage of high harmonics as well. Thus, it helps to improve system efficiency. L type matching network is consisted of one capacitor and one inductor as shown in Fig. 2. The relationship between Z_L and Z_R can be adjusted by matching network. Meanwhile, the voltages of the input and output port can be changed. Thus, the aforementioned matching network can be seen as non-isolated transformer. In the nominal operating point, the impedance Z_L and Z_R are both resistive. However, one shortcoming of above L type structure is that with the variation of Z_R, the impedance of Z_L comes into inductive or capacitive as shown in Fig. 3. It is not conducive to keep soft-switching characteristics of switch in inverter stage.

To address above problem, T type matching network is proposed as Fig. 4 shown. It is consisted of one inductor and two capacitor. With the proposed structure and optimal parameter design, the impedance of Z_L can keep resistive characteristics no matter Z_R changes or not. It means that it is more easy to keep the inverter switch operate in soft-switching condition. Fig. 5 shows the impedance angle curves with the variation of Z_R. It can be seen that when the capacitors are chosen as the same value, the impedance angle can keep as zero with the change of Z_R. According to the duality principle, π type can also be proposed as Fig. 6 shown. As shown in Fig. 7, the same characteristics can be achieved as T type one. With one more capacitor, the two matching networks can achieve higher efficiency among wide load variation range.

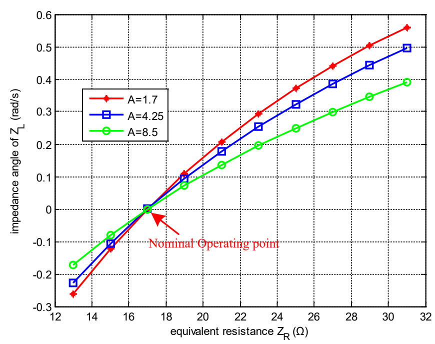


Fig. 3. Angle curve of impedance ZL with change of ZR in L type matching network.

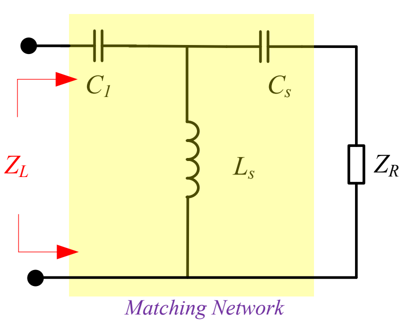


Fig. 4. The circuit diagram of T type matching network.

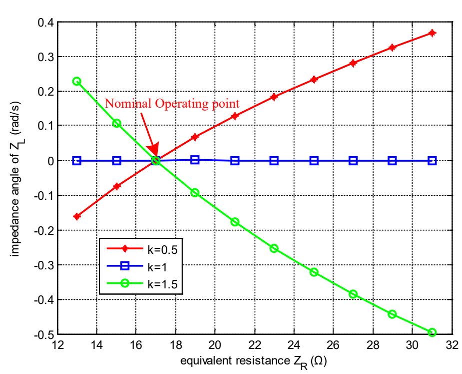


Fig. 5. Angle curves of impedance ZL with change of ZR in T type matching network.

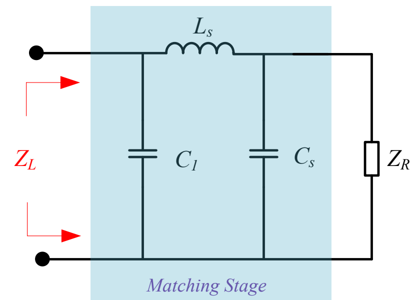


Fig. 6. The circuit diagram of π type matching network.

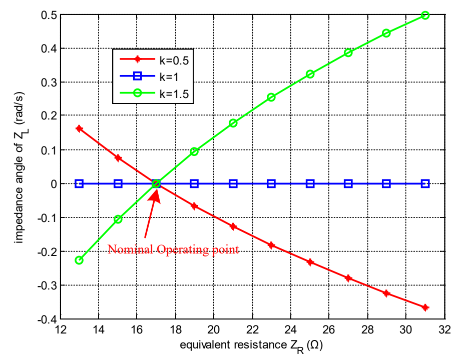
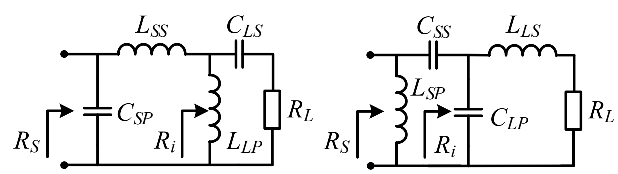


Fig. 7. The circuit diagram of π type matching network.



(a) Lowpass-highpass matching (b) Highpass-lowpass matching

Fig. 8. High-low bandass matching network.

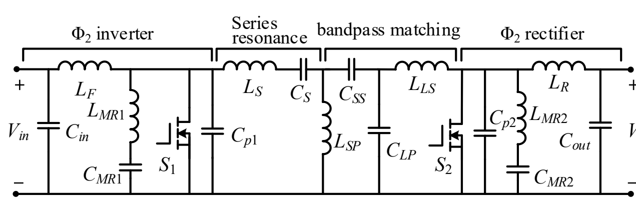


Fig. 9. The circuit of bidirectional and synchronous VHF converter.

Besides aforementioned matching networks, high order matching network is also proposed. As shown in Fig. 8, two high-low bandpass matching networks are proposed. Based on the optimal design method proposed in [76], the high-low pass matching network can keep resistive transformation characteristics at the desired resonant frequency even if the equivalent load increased. Also at resonant frequency, the voltage transformation ratio can keep a constant value. Thus, it can be understood that for VHF converters consisted of same inverter and rectifier circuits, the proposed high-low matching network can be applied to achieve a synchronous structure. As shown in Fig. 9, the bidirectional and synchronous VHF converter based on Class Φ_2 inverter and rectifier stage is proposed.

It also can be seen that aforementioned non-isolated matching networks are very sensitive to the operating frequency. The transformation characteristics varies in different operating frequency. Meanwhile, it can not achieve isolation function, which is necessary in certain application fields. In the following part, isolated stage and converter will be introduced.

B. Topological isolated DC/DC Converter Topology

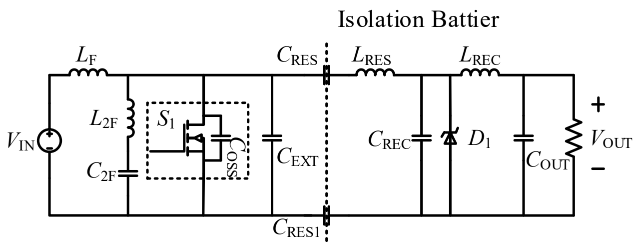


Fig. 10. Diagram of capacitive isolated topology.

Besides the non-isolation structure, the isolation function is expected in many application fields. As shown in Fig. 10, an isolated VHF converter based on class Φ_2 inverter stage is achieved based on capacitive isolation method. With one more capacitor in the return loop of rectifier stage, the isolation function can be effectively achieved. In hundreds of kHz operating frequency, the value and volume of isolation capacitor must be very large. However, in very high frequency condition with reduced energy requirement, the value and volume can be significantly shrink. Also, the parasitic resistance and volume of ceramic capacitor is usually quite lower than magnetic components, which helps to improved system efficiency and power density. Thus, for low voltage isolation requirement, VHF converters with capacitive isolation method can be applied.

However, for higher voltage isolation requirement, lots of problems come to the capacitive isolation method. One problem is that with the increment of rated voltage, the volume of capacitor greatly increases which is not conducive to reduce converter volume. Also, with large capacitor size, the parasitic inductance caused by leads also greatly affects system operation in very high frequency condition. Another problem is that for kilo-volt isolation application, there are almost no high quality capacitor suitable for operating in such high switching frequency. With low quality factor, system suffers lots of loss.

Also, for the circuit in Fig. 10, it can be seen that extra capacitor is needed. For power density sensitive or cost sensitive applications, the component number is expected to be as little as possible. Meanwhile, in very high frequency applications, increasing number of components lead to more tracks and more component leads, it causes unexpected parasitic inductances. Thus, small component account is appreciated in VHF condition. What's more, for floating output conditions, there is large common mode current in the VHF converter, which can be effectively controlled by reducing parasitic capacitance between windings in transformer isolation condition.

Similar as the low frequency conditions, magnetic isolation based on transformer is the most common method. It can be applied in both low voltage and high voltage application fields. For transformer addition, some problems should be solved. One problem is that the leakage inductance and magnetizing inductance affect the operating mode of the VHF converter. In general, the typical mode of one transformer can be shown as Fig. 11. Besides magnetizing inductance, there are leakage inductances both in primary side and secondary side. In low operating frequency, the transformer is expected to be as ideal as possible by minimizing leakage inductance and maximizing magnetizing inductance. Based on magnetic core with high permeability, large magnetizing inductance and small magnetizing current can be achieved. Meanwhile, with advanced winding method, very high coupling coefficient can be realized in low operating frequency. Also, the resonant inductor value is quite large in hundreds of kHz. Thus based on above method, the transformer can be taken as an ideal one which transfers energy from primary side to secondary side.

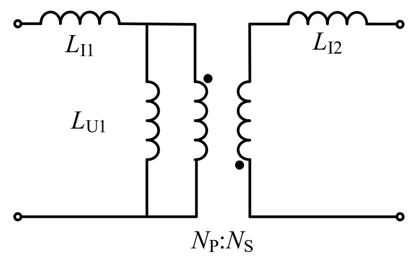


Fig. 11. A two winding transformer model with magnetizing and leakage inductances.

With the increment of operating frequency, the air core transformer with small magnetizing inductance are gradually applied in VHF conditions. Without magnetic core, air core transformer owns loosely coupled coefficients. Also, in VHF converters, the necessary resonant inductor values are tens or hundreds of nH. Thus, the influence caused by leakage inductance and magnetizing inductance must be taken into consideration. One effective way is to leverage leakage inductance and magnetizing inductance as resonant one through optimal topology design.

Fig. 12 shows one example that how to optimize the topology of one isolated VHF converter. Fig. 12(a) shows one isolated DC/DC converter based on Class Φ_2 inverter stage and Class E rectifier stage, where one transformer is added in the middle of these two stages. The leakage inductance in the secondary side can be combined with the resonant inductor. From AC perspective, the DC input source can be seen as short, thus, one port of the transformer primary side can be adjusted to the input side as Fig. 12(b) shown. Within the block, it can be seen that the resonant inductor LF can be combined with the transformer primary side leakage inductance. This example shows how the leakage inductance and magnetizing inductance can be adopted in the VHF isolated converter. Compared with Fig. 12(a) and Fig. 12(c), two resonant inductors are saved, which can help to reduce the count and volume of the components, in order improve the power density. Also, the inductors loss can also be avoided.

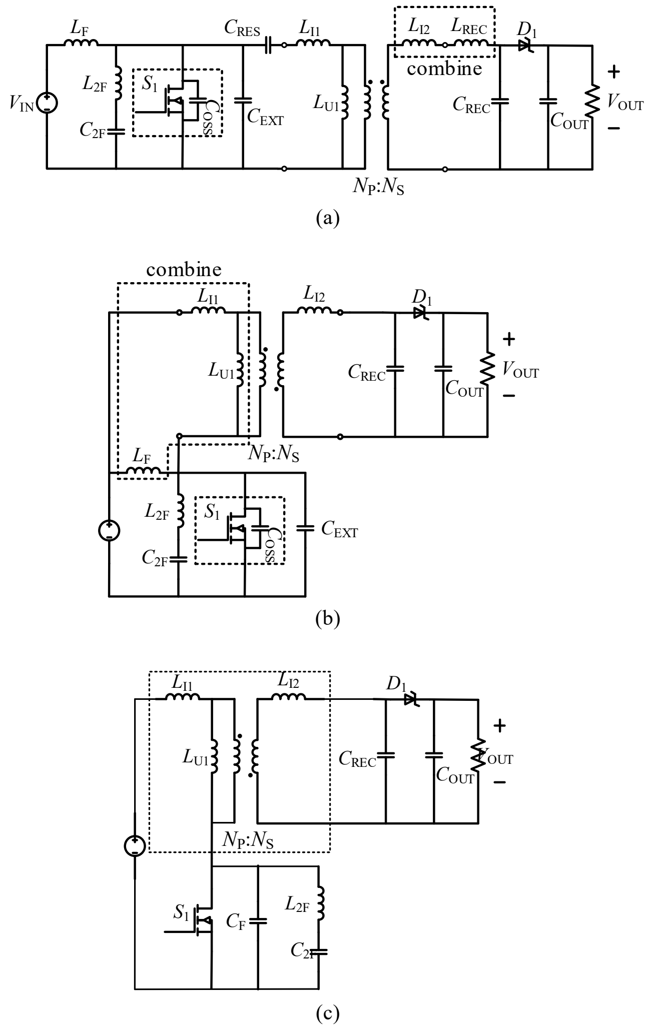


Fig. 12. Transformation from non-isolated converter to isolated converter.

Based on aforementioned converter, the diode in the secondary side can be replaced by a synchronous switch as Fig. 13 shown [77]. The similar method is also adopted in [78] as Fig. 14 shown. With synchronous method, the conduction loss can be reduced with small switch on-resistance. It should be mentioned that corresponding driving circuit in the secondary side are needed in the synchronous structure. Thus, it causes additional driving loss. There should be a tradeoff between conduction loss and driving loss. Another great challenge for synchronous rectification method is that the control signal. Because in VHF condition, the time different between primary side and secondary side is quite small. Some advanced methods have been applied to deal with this problem. Table I shows some typical VHF converters, and corresponding characteristics have been summarized.

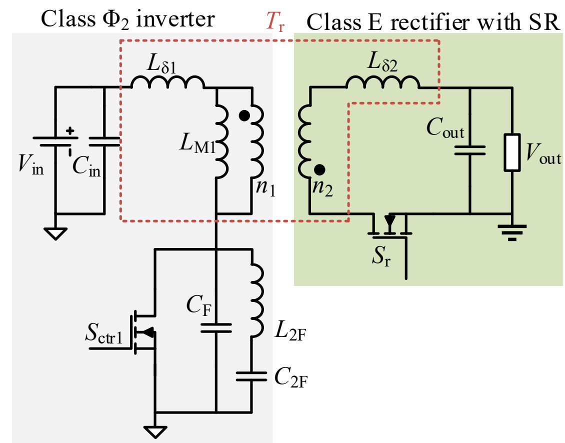


Fig. 13. VHF Circuit based on synchronous switch in [77].

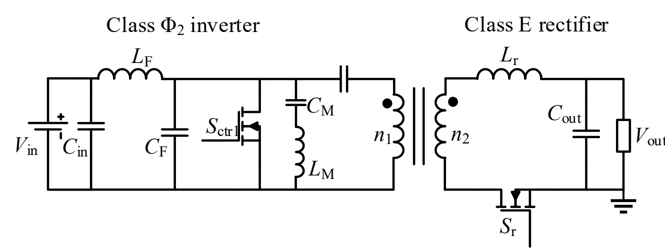


Fig. 14. VHF Circuit based on synchronous switch in [78].

Table I. PROPERTIES COMPARISONS OF SOME TYPICAL HIGH FREQUENCY TOPOLOGIES.

Topology	Switching frequency	Input/output voltage	Output power	Isolation	Inductors number	transformer number	Voltage stress	Efficiency	Power density
Isolated Class Φ_2	20MHz	12V/5V	10W	Yes	3	1	2.6	78%	136 W/in^3
Class E [79]	20MHz	8V/5V	10W	No	3	0	3.5	81.8%	150 W/in^3
Self-driven Class E [80]	13MHz	8V/5V	10W	No	2	0	3.5	83.9%	110 W/in^3
SEPIC [81]	20MHz	5.4V/7V	3W	No	2	0	3.5	82.6%	N.A.
push-pull [82]	30MHz	36V/24V	50W	Yes	7	1	2.6	73.3%	50 W/in^3
Lighting VHF [83]	46MHz	230VAC/ 15V	5.7W	No	2	0	3.5	78%	146 W/in^3
Synchronous Class Φ_2 [84]	10MHz	18V/5V	10W	Yes	3	1	2.6	82%	10 W/in^3

III. MAGNETIC AND SWITCH COMPONENTS

In very high frequency converter, magnetic component is a significant part. In general, the value of inductor and transformer forms an inverse proportional relationship with the operating frequency. However, it cannot be guaranteed that the components volume keeps reducing with increment of operating frequency. The volume scaling is also related with winding loss [85] – [89], core loss and permeability [88]–[95], and heat transfer [95]–[97] under different operating situations.

The research of relationship between size and frequency has gained lots of attention. In [88], under a certain operating frequency, the inductor quality factor with different kinds of loss is deeply investigated. In [89] with limited heat transfer ability, the volume characteristics has been analyzed with various frequencies. Also in [97], with extra efficiency limitation, the property of transformer size has been researched. In [98], the transformer design method considering core loss and winding loss is proposed under different operating frequencies. Besides volume scaling characteristics, the power density property has been explored with above loss and dissipation considerations. According to research, it is demonstrated that because of the loss and heat limitations, the volume cannot always keep reducing, even if the operating frequency keeps promoting.

For magnetic components with core, the core loss imposes an significant for volume minimization. In very high frequency condition, coreless magnetic components can be applied which only suffers from winding loss. Thus, there should a tradeoff between core loss and winding loss when choosing the magnetic component type.

Under a certain inductance and loss situation, the quality factor of inductor can be obtained as follows. Here ε represents the linear scaling factor.

$$Q = \frac{2\pi fL}{R_{AC}} = \frac{2\pi fN^2K_1\varepsilon}{N^2K_3\sqrt{f}} = K_4\varepsilon\sqrt{f} \quad (1)$$

It can be seen that the quality factor forms a proportional relationship with ε and frequency. Therefore, to keep a constant inductance and quality factor at different frequency, the linear dimension can be scaled as $f^{-1/2}$, thus, the total volume varies by $f^{-3/2}$.

Without considering loss limitation, the inductor volume of a certain value can keep reduced with the rate of $f^{-3/2}$ when the operating frequency increases. However, in real application, there must be core loss or winding loss. With the reducing volume, the heat dissipation ability must be weakened, finally reaching the thermal and operating temperature limitation.

As shown in [17], Fig. 15 shows different volume curves with various inductor structure and core materials such as high permeability magnetic material 3F3, low permeability RF material P and aircore structure. Among these three conditions, a small different is that the air core structure is unshielded, while the two cored structures are magnetically shielded. From the curves it can be seen that in low frequency, when the inductor owns good heat dissipation ability, the volume of the two cored inductor scales as $f^{-3/2}$. While the temperature becomes a dominant factor, the volume of inductor scales as $f^{-1/2}$. It can be seen that the previous analysis can effectively capture the inductor characteristics. Also, after reaching certain operating frequency, with loss and temperature limitation, the volume of these two cored inductor increase with the improvement of operating frequency. However, for the air core structure, it can be seen that it always keeps a shrinking trend as increasing operating frequency with enough loss and temperature margin. According to operate frequency range, it can be seen that the air core structure and low permeability cored structure are two optimal choices for VHF magnetic components.

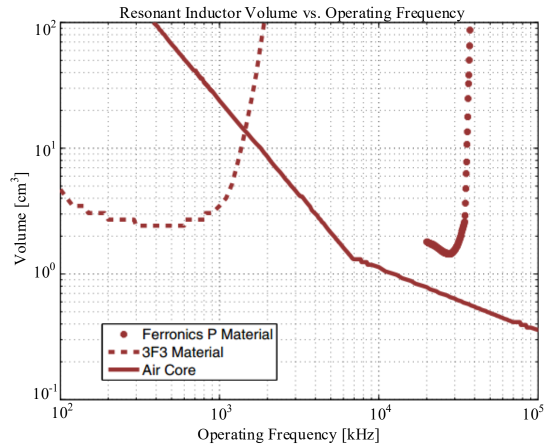


Fig. 15. Comparison between conventional magnetic material (3F3), RF material (P) and coreless inductor volume.

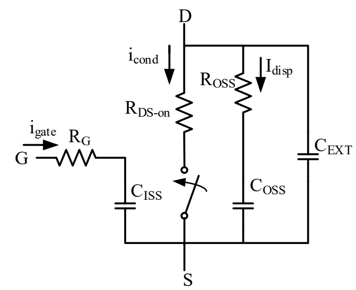


Fig. 16. Simplified device model in lumped form.

TABLE II
DEPENDENCE OF DEVICE LOSS MECHANISMS ON DEVICE PARAMETERS AND FREQUENCY SCALING

Mechanism	Device Dependence	Frequency Dependence
Conduction loss	$\propto R_{ds\text{-}on}$	Independent
Displacement loss	$\propto R_{OSS}C_{OSS}^2$	$\propto f_s^2$
Gating loss	$\propto R_G C_{ISS}^2$	$\propto f_s^2$

Fig. 16 illustrates the simplified switch model in lumped form, which consists of parasitic capacitances and resistances. Here, the parasitic capacitor C_{gd} between switch drain to gate is neglected. Here, R_{DSon}, R_{OSS}, and R_G represents the parasitic resistances in the switch, R_{DSon} causes the conduction loss. C_{ISS} and C_{OSS} represent the input capacitance and output capacitance respectively. A discrete capacitor C_{EXT} is paralleled with the output capacitance to realize the soft-switching characteristics of switch. With the lumped switch model, the switching loss and conduction loss can be analyzed and their relationship with operating frequency can be investigated. Here, the impedance of switch conduction resistance does not change in different frequency. Thus, the conduction loss is only dependent on duty cycle and corresponding current and independent of operating frequency. However, for the loss caused by R_G and R_{OSS}, the current flowing through these two resistors are affected by the operating frequency. It is because that the corresponding branch impedance is dominant by parasitic capacitance which varies a lot with the change of frequency. Thus, it can be seen that at higher operating frequency, the impedance reduces and corresponding branch current increase. The loss caused by R_G

and R_{OSS} form a proportional relationship with f^2. It should be mentioned here that smaller input and output capacitance can also help to reduce corresponding loss, which form a proportional relationship with square capacitance. The corresponding relationship with switch and operating frequency are illustrated in Table II.

With the fast development wide band gap device, the SiC and GaN transistors and diodes show superiority compared with conventional Si devices. With higher carrier mobility, with a certain on resistance, the devices with wide band gap material can be achieved in a smaller area, which helps to reduce the parasitic capacitance. Thus, in VHF condition, the loss can be reduced. With the outstanding advantages, the RF and power switches based on wide band gap material have been the research hotspot in recent years. With further advanced investigation and optimal design strategy, the GaN and SiC devices can achieve better characteristics, which can further improve the performance of VHF converters.

IV. DRIVING METHOD OF VHF CONVERTERS

Besides the research of power conversion architecture, semiconductor and magnetic components in very high frequency converters, high efficiency driving circuit for VHF converter also attracts lots of attention. It is well known that driving circuit loss forms a proportional relationship with switching frequency. Thus, when the system operating frequency increases to tens and hundreds of MHz, the driving circuit loss plays a dominant role in total system loss. In hundreds of kHz conditions, square-wave driving method is the most widely adopted one. It means that a square waveform signal is used to charge and discharge the switch input capacitance in order turn on and turn off the switch. However, with this kind of driving method, the charged and discharged energy during every period is totally dissipated. Thus, in very high frequency condition, resonant driving method is widely adopted.

As shown in Fig. 17, in the driving circuit, a resonant inductor is added in series with the switch gate, which can resonate with the switch input capacitance in order to make use of the capacitor-stored energy. Resonant driving method can greatly ruduce losses compared with square-wave driving method as shown in Fig. 18.

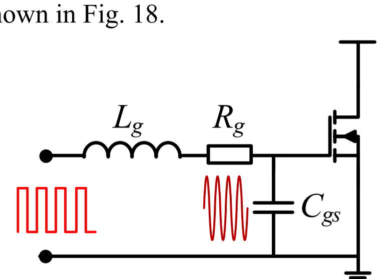


Fig. 17. Diagram of resonant driving circuit.

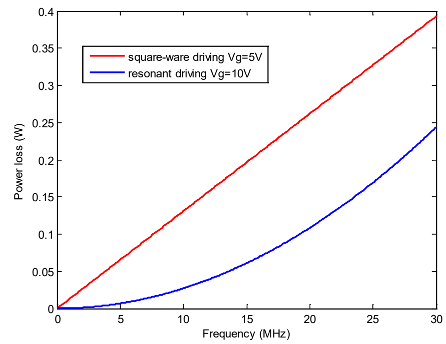


Fig. 18. Driving losses curves of square-wave and resonant driving methods.

On the other hand, it has to be mentioned that though the driving circuit loss based on resonant driving method can be greatly reduced compared with square-wave driving, the switch conduction loss is increased under sinusoidal waveform driving signal. It is because that with resonant driving method, the driving signal is in sinusoidal waveform, it makes the rising edge and falling edge is slower. Thus, during these transition times, the switch on-resistance is in a high value condition which causes a high conduction loss. By increasing the driving voltage amplitude, the switch fully turned-on time can be increased which helps to reduce corresponding loss. However, the driving loss increases in turn with higher driving voltage. Thus, there should be a trade-off between the driving loss and conduction loss according to different system operating situation. Also, the wide band gap semiconductor devices with small input capacitance and on-resistance are greatly expected in very high frequency converters.

Besides the resonant driving circuit based on fundamental waveforms, the high order harmonics can also be adopted. The multi-resonant network is proposed as Fig. 19 shown [99]. Compared these two circuits, it can be seen that an additional inductor and capacitor branch L_{MR} and C_{MR} is paralleled with series resonant inductor L_F. The LC branch is added to introduce third harmonic into the driving waveform. And the corresponding simplified driving voltage with fundamental component and third harmonic component is shown in Fig. 20. It can be seen that with help of third harmonic, the driving signal is in trapezoidal form which make the rising and falling edge steeper. Meanwhile, the energy stored in the input capacitance can also be used during every period.

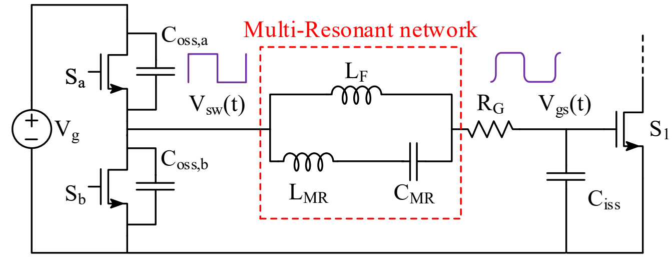


Fig. 19. Multi-resonant driving circuit.

The aforementioned resonant driving method is composed of oscillator and several paralleled inverters. In order to further simplify the necessary components, self-resonant driving circuit is proposed. Fig. 21 shows a VHF self-resonant driving circuit based on series resonant inductor [100]. In the circuit, L_G

is the resonant inductor and V_{bias} represents the bias DC voltage. Based on the inductor and the switch parasitic capacitors, a high-pass filter with the capacitive load is formed. The transfer function V_{ds}/V_{gs} needs to be carefully designed to satisfy the requirements.

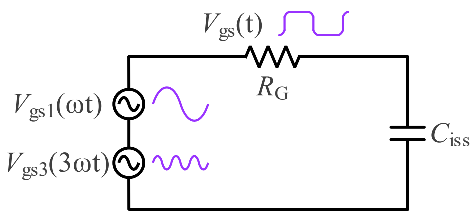


Fig. 20. Simplified driving voltage with fundamental component and third harmonic component.

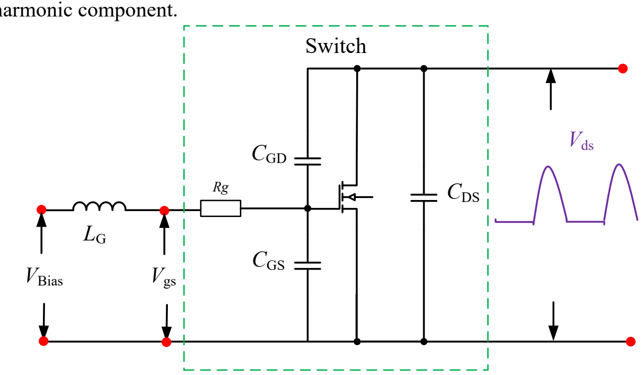


Fig. 21. Circuit of a self-resonant VHF driving circuit.

Fig. 22 shows the waveform diagram of switch gate and drain voltage. Based on the analysis in previous power conversion architecture, the switch drain-to-source voltage is usually in a half-sinusoidal form. Thus, it can be seen that when the driving voltage is low, the switch is off and the drain voltage is high. Meanwhile, when the driving voltage is high, the switch is on and the drain voltage is low. Thus, there should be an almost 180 degree phase different between switch gate and drain voltage.

Fig. 23 shows the Bode diagram of the feed-back network with different series inductance parameters. As can be seen from the figure, the network can achieve about 180 degree phase difference within certain frequency range. By changing the value of inductances, the voltage gain at the operating frequency can be adjusted to meet the amplitude requirement of different switches. The bias voltage V_{bias} can be adjusted to change the switch duty cycle with different threshold voltages. Usually, the duty cycle of the switch is designed to be 0.5, it means that the bias voltage should be around the threshold voltage of the switch. Thus, for different switches, the bias voltage and inductor value should be modified.

However, for the aforementioned self-driving method, besides the switch parasitic capacitance parameters, the seireis inductor is the only variable which can be adjusted. Thus, the characteriscits of self-driving network is mainly determined by the switch. With different parameters, some switches cannot meet the self-driving requirement even within a large inductor range. Thus, to address this problem, additional LC branch are added between switch drain-to-gate or gate-to-source. Fig. 24 and Fig. 25 show the equivalent self-driving networks with LC branch in different locations. With the similar method, the tranfer function between switch drain and gate voltage can be obtained. Fig. 26 and Fig. 27 demenstrate the corresponding Bode plot. It can be seen there are more variables to modify the characteristics to meet the magnitude and phase requirments of self-driving circuit in single-switch VHF converters.

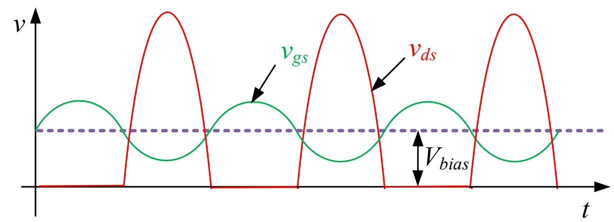


Fig. 22. The diagram of switch gate and drain voltage.

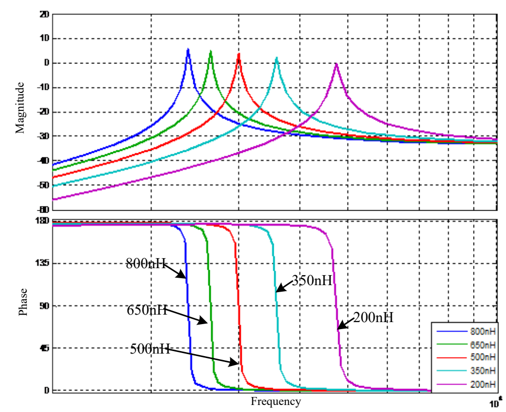


Fig. 23. The bode plots of self-resonant circuit with different inductor values.

Meanwhile, with the LC branch, the current flowing though the can be redistributed compared with the basic situation. It has been proved that the self-driving network with LC branch can help to reduce the driving circuit loss.For half-bridge very high frequency converters, the similar method can be adopted to drive the switches. One challenge is that the phase of the driving signals should be carefully designed to achieve the complementary requirement.

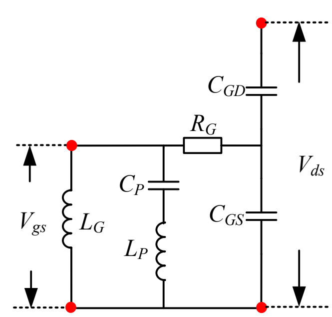


Fig. 24. Equivalent self-driving network with LC branch between gate and source.

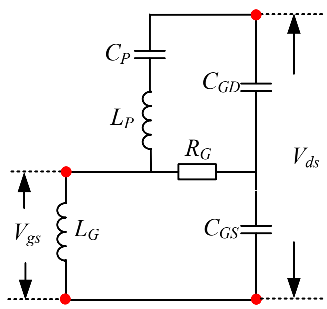


Fig. 25. Equivalent self-driving network with LC branch between source and gate.

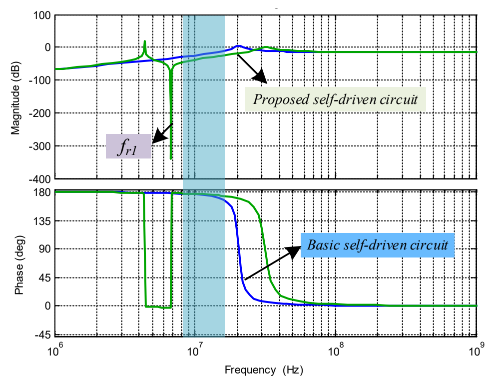


Fig. 26. The bode plots of self-resonant circuit with LC branch between gate and source.

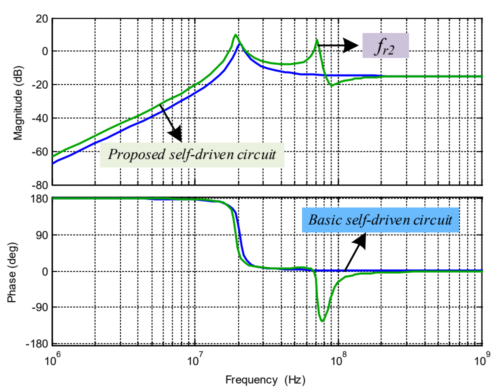


Fig. 27. The bode plots of self-resonant circuit with LC branch between source and gate.

V. CONCLUSION

This paper provides a detailed analysis of VHF converter and corresponding technologies. The first concern of VHF converters is suitable topologies. Different VHF topologies with well soft-switching characteristics have been demonstrated. Different inverter and rectifier stages can be adopted to ahieve VHF covnerters for different input, output and other various application fields. Besides topologies, the magnetic and switch components are introduced. In VHF conditions, the air core or low permeability core structure magnetic components show good performance, which helps to reduce the system volume. Meanwhiel, the switches of wide band gap material are expected in VHF converter to reduce corresponding loss. The parasictic compoents should also be well taken into condideration and absorbed. Finally, the resonant driving and self-driving methods are analyzed. These methods can greatly reduce driving loss. With aforementioned technologies, high performace VHF converters own wide application prospects.

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