International Journal on Applications in Electrical and Electronics Engineering
Volume 1: Issue9 :September 2015 , pp 1- 6. www.aetsjournal.com ISSN (Online) : 2395-3527

An Analysis Of Comparative Class - E Power Amplifier With Series And Quarter Wave Line Shunt Filter

V.Sujatha

Abstract— High power wideband amplifiers are demanded in many application areas, such as software defined radio, electronic warfare (EM), instrumentation systems, etc. The quality of the wireless communication system requires demand for compact, low-cost, and low power transportable transceivers has augmented dramatically. Among the transceiver's building blocks is that the power electronic equipment. Thus, there's a desire for low-priced power electronic equipment. It's necessary to think about the MOSFET gate-to-drain capacitance for achieving the class-E Zero Voltage Switching conditions. As a result, the ability output capability and therefore the power conversion potency are full of the MOSFET gate-to-drain capacitance. The waveform obtained from Analog to Digital simulations and circuit experiments showed the quantitative agreements with the theoretical predictions.

Keyword: Power amplifier, ZVS, MOSFET, ADS

I. INTRODUCTION

The power amplifier (PA) is a key element in transmitter systems, aimed to increase the power level of the signal at its input up to a predefined level required for the transmission purposes. The PA's features are mainly related to the absolute output power levels achievable, together with highest efficiency and linearity behavior [1]. In general, the design of a PA is related to the operating frequency and application requirements, as well as to the available device technology, often resulting in an exciting challenge for PA designers, since not a unique approach is available. Class E could be a comparatively recent electronic equipment format. As in Class D, the device is operated as a switch. Any parasitic capacitance is sometimes damaging. The parasitic drain depletion-region capacitance is resonated with the inductive long once designed. Due to this Category E will satisfy our needs by reaching terribly high efficiencies, conjointly contrary to category D. There are not any short-circuited currents that lead to potency losses [2].

A schematic representation of a SM amplifier is depicted in Fig. 1b. When the active device is turned on, the voltage across its terminals is close to zero and high current is flowing through it. Therefore, in this part of the period the transistor acts as a very low resistance, ideally short circuit (switch closed) minimizing the overlap between the current and voltage waveforms. In the other part of the period, the active device is turned off acting as an open circuit. This style conjointly needs careful choice of the standard shunt-resonant circuit to scale back the high harmonic levels. The distinctive characteristic is that the drain voltage is tube well into the mode region. This key truth has important positive effects on potency measures. As a result of the switch solely activates once the drain to supply voltage is nearly zero. There's little power dissipation within the device. Once the drain voltage is reduced before drain current is drawn, potency will increase. This type of amplification will ideally reach 100 percent potency [3-5].

The conventional style of high-efficient Class-E power electronic equipment needs a high loaded QL-factor of the series filter to satisfy the required harmonic ohms resistance conditions at the device output and to supply curved current flowing to the load. However, if a sufficiently little charge of the loaded quality issue QL is chosen, a high-efficiency broadband operation of the Class-E power electronic equipment may be completed by applying the electrical phenomenon compensation technique [4]. While Class E and related inverters have been employed in applications with variable effective load resistance, a simple and effective methodology for designing inverters for such conditions is lacking. There has been some theoretical work on design of Class E inverters that are insensitive to load variations. However, the results are complex, making design insight difficult, and tend to lead to designs that have very high circulating currents, which hurts efficiency [6,7].

II. CLASS-E ZVS POWER AMPLIFIER WITH MOSFET

The MOSFET's nonlinear drain-to-source capacitance is an important part to satisfy the class-E condition with a high accuracy for getting dynamical conversion potency at high in operation frequencies. However, the output power and power conversion potency square measure necessary parameters to judge of the class-E power electronic equipment performance. Therefore, it's needed to get the look equations for the class-E power electronic equipment with the required output power to satisfy the class-E condition. The class-E nominal conditions square measure ZVS at the side of zero voltage spinoff switches. On the opposite hand, the class-E sub-nominal condition is outlined, once solely the ZVS condition is happy. Each class-E nominal conditions and therefore the class-E sub-nominal condition square measure influenced by the shunt capacitance. Usually, the MOSFET nonlinear drain-to-source

Dr V.Sujatha, Principal, Shree Sathyam College of Engineering and Technology, Sankari, (Email : sujatha1291972@gmail.com).

International Journal on Applications in Electrical and Electronics Engineering
Volume 1: Issue9 :September 2015 , pp 1- 6. www.aetsjournal.com ISSN (Online) : 2395-3527

parasitic capacitance and therefore the external linear capacitance between the drain and therefore the supply of the MOSFET within the parallel type offer the full needed shunt capacitance. Although the external linear shunt capacitance is dominant at low in operation frequency, however, the impact of the MOSFET nonlinear drain-to-source parasitic capacitance will increase because the in operation frequency will increase. Therefore, it's necessary to contemplate the nonlinearity of the shunt capacitance not just for the class-E nominal conditions however conjointly for the class-E sub-nominal condition [8-10].

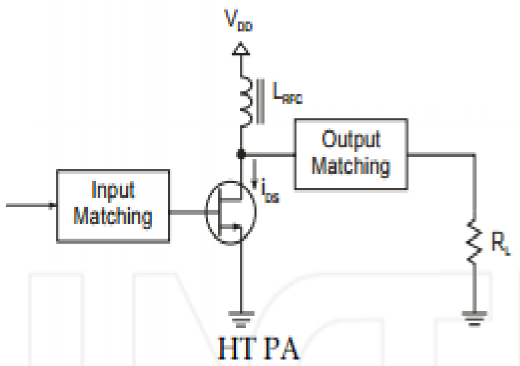

Fig.1 Class E inverter topology

The circuit topology of the best class-E power electronic equipment that consists of a MOSFET because of the presence of the switch part S, the dc-feed inductance L RFC, shunt capacitance Cds, and series resonant filter L-C-R. The switch is in the off state for zero $\leq \theta < \Pi$ and is within the state for $\Pi \leq \theta < 2\Pi$. The MOSFET turns off and on or else at θ = zero and π [11].

Assumptions

The analytical expression of the waveform and design equations for the class-E sub nominal condition is carried out under the following assumptions: The shunt capacitance is barely the MOSFET drain-to-source nonlinear parasitic junction capacitance, that is represented by a nonlinear perform Cds = Cj0 / (1+Vs/ Vbi) .wherever V_{bi} is that the integral potential, whose typical worth is within the region from 0.5 to 0.9 V for Si MOSFETs, Vs is that the voltage between the drain and supply, Cj0 is that the junction capacitance at Vs = zero, and m is that the grading constant.

- The switch voltage satisfies the ZVS condition Q=**ω**L/R
- MOSFET, works as a perfect switch, namely, the MOSFET has zero switch-on state resistance and infinite switch-off state resistance.
- The dc feed inductance LRFC is high enough to IDD through the dc feed inductance.
- The resonant inductance L is split into L1 and L2.
- The resonant filter L1 − C is a perfect resonant filter for the operational frequency, that has zero electrical phenomenon and yields zero part shift at the operational frequency.

III. ZVS DESIGN

In this section, the fig 1 shows the class-E power electronic equipment with a nonlinear shunt capacitance underneath the sub nominal condition [12]. It's assumed that the shunt capacitance consists of solely the MOSFET nonlinear drain to-supply parasitic capacitance, which may be varied indiscriminately. The grading constant m of the MOSFET body junction diode is taken into account as associate adjustment parameter that gives correct style to satisfy the given output power, peak switch voltage, and therefore the class-E ZVS condition.

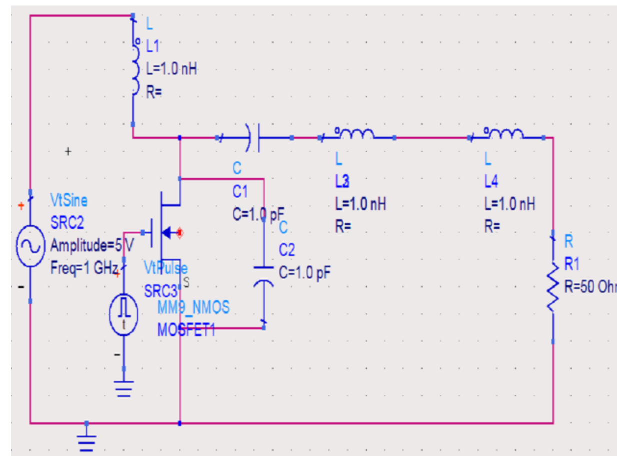

Fig.2. Class-E power Amplifier circuit

In a real class-E power electronic equipment circuit, the nonzero equivalent series resistances of every element and therefore to activate state resistance of the MOSFET result in power losses within the circuit. The active device behaviors ought to be like a perfect switch for getting high-efficiency. Fig. shows the equivalent circuit of the class-E power electronic equipment, wherever the ESRs of every element are thought of. During this paper, the MOSFET on-state resistance R_s, Associate in Nursing ESR of the load network rLC, associate in nursing an ESR of the dc-feed inductance rLRFC is thought of to get the facility dissipation's analyses. Generally, the ESRs of the MOSFET gate-to-drain and drain-to-source parasitic capacitances are a lot of under the opposite ESRs. Therefore, the facility dissipation at the ESRs of the MOSFET gate-to-drain and drain-to-source parasitic capacitance is neglected [13] .The ZVS operation is obtained at five rates. As a result, for the primary style example the measured power conversion potency is 89.7% with the output power 8.96 W. For the second style example, the measured power conversion potency is 91.2% with the output power 39.69 W. It will be ended from these results that it's vital and effective to think about the non linearity of the MOSFET drain-to-source capacitance together with the sub nominal condition for coming up with of a class-E power electronic equipment with a given output power and peak switch voltage, wherever the grading constant m is employed as associate in nursing adjustment parameter. However, the impact of the duty magnitude relation and MOSFET gate-to-drain capacitance to style of the class-E ZVS power electronic equipment are vital and fascinating analysis topic, we should always address within the future work.

IV. CLASS-E POWER AMPLIFIER DESIGN WITH FILTERS

Modern wireless communication systems, it's needed that the ability electronic equipment may operate with high potency, high one-dimensionality, and low harmonic output level at the same time. To extend potency of the ability electronic equipment, it is able to use a switch mode class-E, inverse class-F, or mixed class-E/F mode technique.

An analysis of single-ended Class-E mode with shunt capacitance and shunt filter with specific derivation of the idealized optimum voltage and current waveforms and cargo network parameters with their verification by frequency domain simulations with five hundredth duty magnitude relation is mentioned. The circuit style with transmission lines at a pair of 1/4 Gc is mentioned and analyzed. So as to scale back the voltage peak issue, the load network parameters may be rearranged to correspond to Class-E/F3 mode by providing a short-circuit condition at the third harmonic once the second-harmonic tank is connected serial to the shunt filter[14] .

Broadband capability of a Class-E mode with shunt filter exploitation electrical phenomenon compensation technique has been in contestable by 2 examples, one with lumped components and also the alternative with transmission line components. The check board of transmission-line broadband Class-E GaN HEMT power electronics equipment with shunt filter was measured and superior results with the output power of around forty one dBm, average drain potency of sixty eight, and power gain of regarding nine dB were achieved across the waveband from 1.4 to 2.7 GHz. Class E with shunt capacitance and series filter wherever a shunt filter is employed rather than a series filter, so leading to a brand new load-network configuration, which might give not solely Class E shift conditions however conjointly broadband capability with high potency across the wide waveband.

The theoretical assumptions, simulation and experimental results for Class-E mode with shunt capacitance and shunt filter by providing an in depth analytical insight into the circuit analysis, specific derivation of optimum voltage and current waveforms and load-network parameters, and cargo network transmission-line style techniques square measure explained and mentioned. The optimum parameters of single-ended Class-E power electronic equipment with shunt capacitance associate in nursing shunt filter may be determined supported as an analytical derivation of its steady-state collector voltage and current waveforms.

Fig. 1 shows the fundamental circuit configuration of a Class-E power electronic equipment with shunt electrical condenser and shunt filter, wherever the load network consists of a shunt electrical condenser C, a series inductance L, a obstruction electrical condensers, a shunt essentially tuned L C circuit, and a load electrical device R. during this case, the shunt L C circuit operates as a harmonic filter making zero ohmic resistance at the second- and higher-order harmonics rather than the open-circuit harmonic conditions adore the standard Class-E power electronic equipment with shunt capacitance and series filter. In a very common case, a shunt capacitance C will represent the intrinsic device output capacitance and external circuit capacitance value-added by the load network. The dc power offer is connected by Associate in Nursing RF choke with infinite electrical phenomenon at the elemental and any higher order harmonic element. The active device is taken into account a perfect switch that's driven at the operational frequency to supply fast shift between its on-state and off state operation conditions.

Circuit analysis following several assumptions is introduced:

- The transistor has zero saturation voltage with initial zero saturation
- Low Resistance, infinite off-resistance, and its switching are instantaneous and lossless.
- The shunt capacitance is assumed to be constant at all stages.
- The shunt L C filter has zero impedance at the second and higher-order harmonics.
- There is no loss in the circuit except the load R. For simplicity, a 40 to 60 % duty ratio is used.

The optimized load-network parameters of the various category-E modes together with Class E with series filter, category E with quarter wave line, and sophistication E with shunt filter category E with shunt filter offers the larger price of the shunt capacitance C for constant load R and far higher price of the utmost operational frequency fmax for constant dc offer voltage Vcc device output capacitance Cout, and output power Pout, compared to category E with shunt capacitance and series filter. At constant time, distinction between category E with quarter wave line thus phistication E with shunt filter isn't so vital as a result of the quarter wave line being grounded at its finish through bypass condenser operates for even harmonics as a shunt filter.

V. DESIGN WITH TRANSMISSION LINES

The circuit schematics of a high-efficiency transmission-line Class-E power electronic equipment with shunt capacitance and shunt filter square measure shown in Fig 2, wherever the optimum load resistance R is matched to the quality load electrical phenomenon RL=50 Ω at the elemental frequency employing a quarter wave conductor, or employing a conductor L-type electrical phenomenon electrical device. Here, the shunt harmonic filter consists of forty five degree contact and electrical circuit stubs to make short-circuit conditions at even harmonics. to make a short-circuit condition at the third harmonic at the right-hand aspect of the series electrical device delineated by a short-length series conductor with the characteristic electrical phenomenon Z_0 and electrical length θ,

International Journal on Applications in Electrical and Electronics Engineering
Volume 1: Issue9 :September 2015 , pp 1- 6. www.aetsjournal.com ISSN (Online) : 2395-3527

the series conductor with electrical length of sixty degree associate degreed an open-circuit stub with electrical length of thirty degree square measure used.

The ADS simulation setup accustomed acquire the nominal Class-E operation mode with infinite RF choke in frequency domain, wherever the input supply Vf_Pulse represents a voltage supply with Fourier series growth of periodic rectangular wave with totally different pulse breadth characterized by a requirement magnitude relation utilized in a harmonic balance machine. Generally, exploitation frequency domain allows the general simulation procedure to be abundant quicker than that in time domain and may takea number of seconds the optimization procedure may be applied with reference to potency as associate degree optimization parameter. Since the simulation time is incredibly short, variety of iterations will considerably be multiplied for a lot of accuracy.

For a Class-E load network with shunt capacitance shown in fig.3, as a PAE higher than five hundredth was achieved at intervals the frequency vary from 1 to 8 GHz.As a result to extend high-efficiency frequency information measure, the broadband Class-E technique supported a electrical phenomenon compensation principle with a mixture of the series and shunt resonant circuits may be used. Generally, terribly broadband power electronic equipment style employs associate degree input lossy LCR matching circuit to attenuate the input come back loss associate degreed output power variations over terribly wide frequency bandwidths with an LC output network to make amends for the device output electrical phenomenon. As an alternate, to produce associate degree input broadband matching over associate degree octave information measure it's potential to use a multi section matching electrical device consisting of stepped transmission-line sections with totally different characteristic impedances and electrical lengths [12]. Such associate degree input matching structure is convenient in sensible implementation as a result of there ought no to use any standardization capacitors

VI. SIMULATION RESULTS AND POWER ANALYSIS

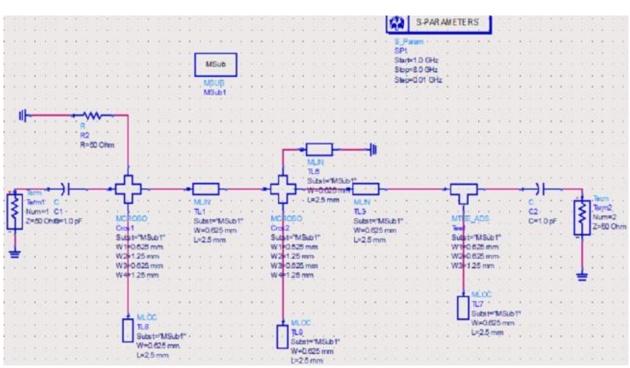

Fig. 3.Circuit schematic of transmission-line Class-E GaN HEMT power amplifier with shunt filter with capacitor

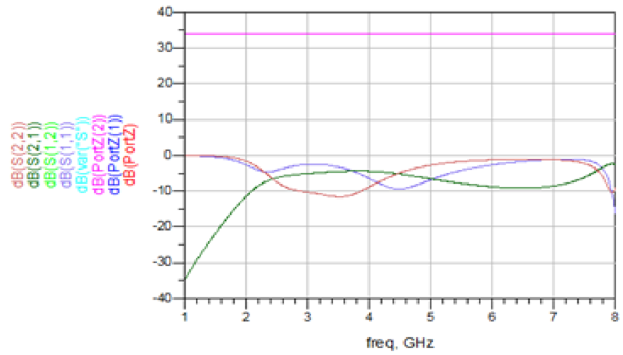

Fig.4.Simulation result of transmission-line Class-E amplifier

Fig .4 shows the waveforms obtained from theoretical expressions, ADS simulations, and circuit experiments for the circuit design example.

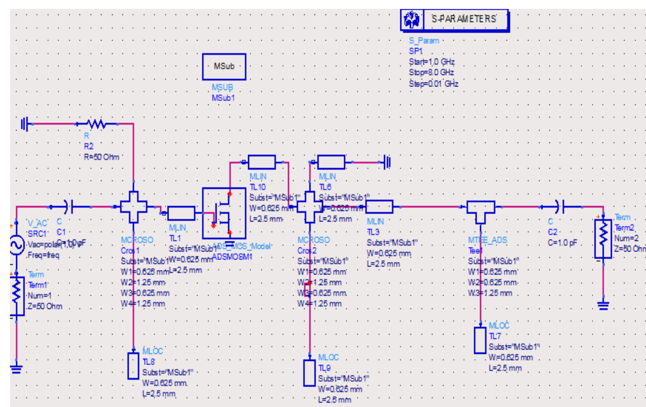

Fig.5. Circuit schematic of transmission-line Class-E GaN HEMT power amplifier with shunt filter with capacitor

Fig 4 and 5 that the transmission-line Class-E operation is obtained at 8 MHz as a result, for the first design example the measured power conversion efficiency η is 92.1% with the output power 10 W.

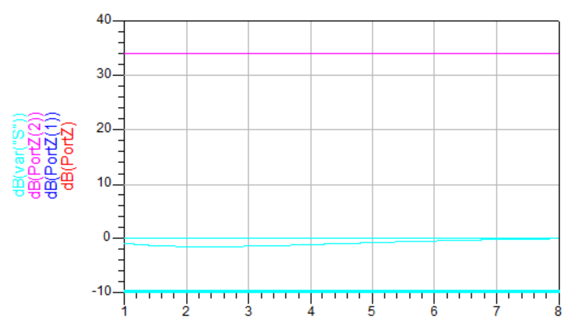

Fig.6. Simulation result of Class-E GaN HEMT power amplifier with shunt filter with capacitor

The circuit experiments and ADS simulations for two class-E power amplifier examples are carried out to validate the analytical expressions. Fig. 7 shows the waveforms obtained from theoretical expressions, ADS simulations, and circuit

International Journal on Applications in Electrical and Electronics Engineering
Volume 1: Issue9 :September 2015 , pp 1- 6. www.aetsjournal.com ISSN (Online) : 2395-3527

experiments for the first circuit design example, which indicate the validity of the analytical expressions.

Table.I Class E Zvs Power Amplifier With Series Filter, Shunt Filter At Quarter Wave Line

Parameters	Theoretical Result	Simulated Result Circuit 1	Simulated Result Circuit 2	Simulated Result Circuit 3
R	50Ω	50Ω	50Ω	50Ω
D	0.5	0.5	0.5	0.5
VDD (V)	15	13	15	14
f(MHZ)	8	8	8	8
Idd in mA	0.61	0.62	0.65	0.60
L(nH)	10nH	10nH	10nH	10nH
C(pF)	10pF	10pF	10pF	10pF
Power in (W)	12.30	10.11	9.31	8.35

From the table. I the idealized simulation setup of a 10-W broadband Class-E power electronic equipment circuit with shunt filter designed to work across the band from 1 to 8 GHz and supported a GaN HEMT Cree CGH40010 device, wherever each the input matching circuit and cargo network area unit composed of ideal microstrip transmission lines. The nominal Class-E load resistance calculated for Pout=10W and Vdd = twenty four from is capable regarding twenty five Ω. during this case, the conductor broadband Class-E load network with shunt filter having a 25-Ω load is delineate by the open- and short-circuit stubs commutation the lumped electrical device and electrical device, severally, every having a characteristic electrical phenomenon of fifty Ω and electrical length of 45degree at two.0 GHz. further series conductor with 35-Ω characteristic electrical phenomenon and of 1 / 4 wavelength at the high information measure frequency of two.7 GHz is employed to match associate idealized 25-Ω load with a regular 50-Ω load. As a result, associate output power of over forty one dBm with a power gain of around ten decibel was simulated for associate input power of thirty one dBm.

VII. CONCLUSION

The theoretical analysis of a unique single-ended Class-E mode with shunt capacitance and shunt filter with specific derivation of the idealized optimum voltage and current wave forms and load-network parameters with their verification by frequency domain simulations with a five hundredth duty magnitude relation is bestowed. However, the targeted bandwidth within this project is very large. In view of this, two bandwidth extension methods (lossy matching and reactive matching) were explored. Among the lossy matching networks, R-L shunt and R shunt networks were analyzed in this work. With these matching techniques, a quite flat gain in the bandwidth from 0.6 GHz to 3 GHz can be obtained for the designed. The perfect collector voltage and current wave forms demonstrate a clear stage of 100 percent potency while not overlapping between one another. The circuit style with transmission lines at in operation frequency of 2.14 G mentioned and analyzed. so as to scale back the voltage peak issue, the load network parameters will be rearranged to correspond to Class-E/F3 mode by providing a short-circuit condition at the third harmonic once the second-harmonic tank is connected asynchronous to the shunt filter. Broadband capability of a Class-E mode with shunt filter victimization electrical phenomenon compensation technique has been incontestable by 2 examples, one with lumped components and therefore the alternative with transmission-line components. The take a look at board transmission-line broadband Class-E GaN HEMT power electronic equipment with shunt filter was measured and high performance results with the output power of around forty one dBm, average drain potency of sixty eight, and power gain of regarding nine decibel were achieved across the waveband from 1.4 to 2.7 GHz. The design methodology relates to circuit transformations on classical class E designs, and demonstrate how the transformation-based approach can be employed to reconfigure designs with higher-order tunings for variable-resistance operation. It is expected that the presented work be valuable in applications where single switch inverters are operated under variable-resistance load operation, such as in dc-dc converters and out phasing power amplifiers.

REFERENCES

[1] M. K. Kazimierczuk and K. Puczko, "Class E tuned power amplifier with anti-parallel diode or series diode at switch, with any loaded Q and switch duty cycle," *IEEE Trans. Circuits Syst.*, vol. 36, no. 9, pp. 1201–1209, Sep. 1989.

[2] M. K. Kazimierczuk and K. Puczko, "Exact analysis of class E tuned power amplifier at any Q and switch duty cycle," *IEEE Trans. Circuits Syst.*, vol. CAS-34, no. 2, pp. 149–159, Feb. 1987.

[3] H. Sekiya, I. Sasase, and S. Mori, "Computation of design values for class E amplifiers without using waveform equations," *IEEE Trans.Circuits Syst. I, Fundam. Theory Appl.*, vol. 49, no. 7, pp. 966–978, Jul. 2002.

[4] T. Suetsugu and M. K. Kazimierczuk, "Comparison of class E amplifier with nonlinear and linear shunt capacitance," *IEEE Trans. Circuits Syst.I, Fundam Theory Appl.*, vol. 50, no. 8, pp. 1089–1097, Aug. 2003.

[5] T. Suetsugu and M. K. Kazimierczuk, "Analysis and design of class E amplifier with shunt capacitance composed of nonlinear and linear capacitances,"*IEEE Trans. Circuits Syst. I, Reg. Papers*, vol. 51, no. 7, pp. 1261–1268, Jul. 2004.

[6] X. Wei, H. Sekiya, S. Kuroiwa, T. Suetsugu, and M. K. Kazimierczuk, "Design of class E amplifier with MOSFET linear gate-to-drain and nonlinear drain-to-source capacitances," *IEEE Trans. Circuits Syst. I, Reg. Papers*, vol. 58, no. 10, pp. 2556–2565, Oct. 2011.

[7] M. Hayati, A. Lotfi, M. K. Kazimierczuk, and H. Sekiya, "Analysis and design of class E power amplifier with MOSFET parasitic linear and nonlinear capacitances at any duty ratio," *IEEE Trans. Power Electron.*, vol. 28, no. 11, pp. 5222–5232, Nov. 2013.

[8] B. Yuan, X. Yang, D. Li, Y. Pei, J. Duan, and J. Zhai, "A current-fed multi resonant converter with low circulating energy and zero-current switching for high step-up power conversion," *IEEE Trans. Power Electron*, vol. 26, no. 6, pp. 1613–1619, Jun. 2011.

[9] Y.-T. Chen, S. Shiu, and R. Liang, "Analysis and design of a zero-voltage switching and zero-current-switching interleaved boost converter," *IEEE Trans. Power Electron*, vol. 27, no. 1, pp. 161–173, Jan. 2012.

[10] H. Wang, H. Chung, and A. Ioinovici, "A new concept of high-voltage DC–DC conversion using asymmetric voltage distribution on the switch pairs and hybrid ZVS–ZCS scheme," *IEEE Trans. Power Electron*, vol. 27, no. 5, pp. 2242–2259, May. 2012.

[11] T.-H. Hsia, H.-Y. Tsai, D. Chen, M. Lee, and C.-S. Huang, "Interleaved active-clamping converter with ZVS/ZCS features," *IEEE Trans Power Electron.*, vol. 26, no. 1, pp. 29–37, Jan. 2011.

[12] A. Safaee, D. Yazdani, A. Bakhshai, and P. K. Jain, "Multiblock soft switched bidirectional AC–AC converter using a single loss-less active snubber block," *IEEE Trans. Power Electron.*, vol. 27, no. 5, pp. 2260– 2272, May. 2012.

[13] K. Krishnamurthy, D. Green, R. Vetury, M. Poulton, and J. Martin, "0.5–2.5, 10 W MMIC power amplifier in GaN HEMT technology," in *2009 IEEE Compound Semicond. Integr. Circuits Symp. Dig.*, pp. 1–4.

[14] M. Helaoui and F. M. Ghannouchi, "Optimizing losses in distributed multiharmonic matching networks applied to the design of an RF GaN power amplifier with higher than 80% power-added efficiency," *IEEE Trans. Microw. Theory Tech.*, vol. 57, pp. 314–322, Feb. 2009.

[15] A. Grebennikov, "Multiband Doherty amplifiers for wireless applications," *High Freq. Electron.*, vol. 13, pp. 30–46, May 2014.