

**147**

**US PATENTS AWARDED**

**Center for Power Electronics Systems (CPES)**

VTIP 16-109

*Matrix Transformer and Winding Structure*

Chao Fei, Fred C. Lee, Qiang Li

[US PATENT: 10,910,140](#)

Issued: February 2, 2021

Abstract: A matrix transformer particularly suited to large voltage step-down, high current applications achieves increased good current sharing uniformity or air gap and electrical characteristics and reduced or eliminating termination losses, core losses and winding losses with a unitary magnetic core structure featuring sheets of magnetic material and a two-dimensional array of pillars on which windings, oriented in opposite directions on pillars that are adjacent in orthogonal directions, can be formed or placed comprising metallization on or embedded in a printed circuit board (PCB) structure. Magnetic flux density is reduced by at least one-half by dividing the magnetic flux in each pillar into two paths of increased width in the sheets of magnetic material. Magnetic flux density may be further decreased and flux uniformity improved by extending the sheets of magnetic material beyond a periphery defined by the pillar array.

VTIP 18-123

*Three-Phase, Three-Level Inverters and Methods for Performing Soft Switching with Phase Synchronization*

Nidhi Haryani, Sungjae Ohn, Rolando Burgos, Dushan Boroyevich

[US PATENT: 10,886,860](#)

Issued: January 5, 2021

Abstract: A three-phase, N-level inverter and method are disclosed. A circuit topology of the inverter comprises first, second and third sets of switches and first, second and third inductors. Each switch comprises at least first, second and third terminals, the first terminals being control terminals. The first terminals of the first, second and third inductors are electrically coupled to the first, second and third sets of switches, respectively. A current controller performs a control algorithm that causes it to output first, second and third sets of gating signals to the control terminals of the switches of

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the first, second and third sets of switches, respectively, to cause them to be placed in an on state or an off state in a particular sequence to perform zero voltage switching while maintaining synchronization of the three phases of the three-phase, N-level inverter.

### VTIP 19-022

#### *Bidirectional Three-Phase Direct Current (DC)/DC Converters*

Hao Xue, Bin Li, Qiang Li, Fred C. Lee

[US PATENT: 10,873,265](#)

Issued: December 22, 2020

Abstract: A bidirectional three-phase direct current (DC)/DC converter and method are disclosed. The converter comprises a primary side comprising a DC bus having a positive side and a negative side, a first set of rectifiers connected between the positive side and the negative side of the DC bus, a first set of M resonant tanks connected to a respective rectifier of the first set of rectifiers and a first set of M transformers. Each transformer is connected to a respective resonant tank. Each resonant tank comprises a resonant capacitor and a resonant inductor. The secondary side of the converter is fully symmetrical to the primary side of the converter to ensure that the conversion gain in the forward and reverse directions is the same.

### VTIP 18-089

#### *Interleaved Converters with Integrated Magnetics*

Chao Fei, Bin Li, Fred C. Lee, Qiang Li, Hongfei Wu

[US PATENT: 10,770,081](#)

Issued: September 29, 2020

Abstract: Three-phase interleaved LLC and CLLC resonant converters, with integrated magnetics, are described. In various examples, the primary sides of the phases in the converters rely upon a half-bridge configuration and include resonant networks coupled to each other in delta-connected or common Y-node configurations. The secondary sides of the phases can rely upon a full-bridge configurations and are coupled in parallel. In one example, the transformers of the phases in the converters are integrated into one magnetic core. By changing the interleaving structure between the primary and secondary windings in the transformers, resonant inductors of the phases can also be integrated into the same magnetic core. A multi-layer PCB can be used as the windings for the integrated magnetics.

### VTIP 16-029

#### *DC-DC Power Converter*

Shigeharu Yamagami, Khai Doan The Ngo

[US PATENT: 10,778,110 \(Sponsored by Nissan, NOT IP SHARING\)](#)

## CPES Patent Portfolio

Issued: September 15, 2020

Abstract: A power converter is basically provided with at least three switching circuits, at least one power source, at least one load, and a resonant circuit. Input terminals of the switching circuits are connected to either the at least one power source or the at least one load, and output terminals of the switching circuits are electrically serially connected to the resonant circuit to form a closed circuit.

### VTIP 16-022

#### *Non-Linear Droop Control*

Fang Chen, Rolando Burgos, Dushan Boroyevich

[US PATENT: 10,770,988](#)

Issued: September 8, 2020

Abstract: Aspects of non-linear droop control are described herein. In one embodiment, a system includes a first power converter or source configured to provide power to a bus, a second power converter or source configured to provide power to the bus, and a load electrically coupled to the bus. The system also includes a controller configured to adjust a droop resistance associated with the first power source according to a continuous non-linear function based on an amount of current supplied to the load by the first power source. The system can also include a second controller configured to adjust a droop resistance associated with the second power source according to the continuous non-linear function (or another continuous non-linear function). The use of the continuous non-linear functions achieves tighter voltage regulation particularly at lower loads and better load sharing at higher loads.

### VTIP 15-067

#### *Inverse Charge Current Mode (IQCM) Control for Power Converter*

Syed Bari, Fred C. Lee, Qiang Li

[US PATENT: 10,673,328](#)

Issued: June 2, 2020

Abstract: An amount of charge transferred by a power converter is estimated by developing a signal that is a combination of signals representing an output voltage of a power converter and an inductor current of the power converter, charging a capacitor with a current proportional to that signal and comparing a voltage developed across the capacitor due to that charging to develop a signal for initiating a pulse to control input of power from a voltage source to the power converter. By using a signal developed in this way, response to both step-up and step-down transients can be improved and, in multi-phase embodiments, ripple cancellation problems such as noise susceptibility and loss of pulse generation can be entirely avoided.

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### VTIP 18-113

#### *Switched Capacitor Converters with Multi Resonant Frequencies*

Owen Jong, Qiang Li, Fred C. Lee

[US PATENT: 10,658,928](#)

Issued: May 19, 2020

Abstract: Various examples are provided related to switched-capacitor converters (SCCs) with multi resonant frequencies. In one example, a multi resonant SCC (MRSCC) includes a series of switches coupled between an input voltage and an output connection; a pair of diodes coupled across the output connection; and a resonant circuit coupled at a first end between first and second switches of the series of switches and at a second end between the pair of diodes. The resonant circuit can comprise a resonant tank including a first capacitor and a resonant inductor, and a resonant component in parallel with at least a portion of the resonant tank. The resonant component can be connected across the resonant tank or across the resonant inductor. The MRSCC topology can also be used with higher voltage conversion ratio converters.

### VTIP 17-015

#### *Variable DC Link Converter and Transformer for Wide Output Voltage Range Applications*

Bin Li, Zhengyang Liu, Fred C. Lee, Qiang Li

[US PATENT: 10,454,381](#)

Issued: October 22, 2019

Abstract: A variable direct current (DC) link power converter is described. In one example, the power converter includes a first converter stage configured to convert power from a power source to power at an intermediate link voltage and a second converter stage configured to convert the power at the intermediate link voltage to power for charging a battery. The power converter further includes a control system having an intermediate link voltage regulation control loop configured, in a first mode of operation, to regulate the intermediate link voltage through the first converter stage based on a voltage of the battery, and a ripple regulation control loop configured to sense a charging current for the battery and regulate a gain of the second converter stage based on the charging current to reduce ripple in the charging current. A new configuration of transformer suitable for use with the power converter is also described.

### VTIP 16-007

#### *Modular Multilevel Converter Capacitor Voltage Ripple Reduction*

Yadong Lyu, Yi-Hsun Hsieh, Fred C. Lee, Qiang Li

[US PATENT: 10,404,064](#)

## CPES Patent Portfolio

Issued: September 03, 2019

Abstract: Aspects of capacitor voltage ripple reduction in modular multilevel converters are described herein. In one embodiment, a power converter system includes a modular multilevel converter (MMC) electrically coupled and configured to convert power between two different power systems. The MMC includes one or more phase legs having a cascade arrangement of switching submodules, where the switching submodules include an arrangement of switching power transistors and capacitors. The MMC further includes a control loop including a differential mode control loop and a common mode control loop. The differential control loop is configured to generate a differential control signal based on a target modulation index to reduce fundamental components of voltage ripple on the capacitors, and the common mode control loop is configured to inject 2nd order harmonic current into a common mode control signal to reduce 2nd order harmonic components of the voltage ripple on the capacitors.

VTIP 15-049

### *Coupled Inductor for Interleaved Multi-Phase Three-Level DC-DC Converters*

Mingkai Mu, Sizhao Lu, Yang Jiao, Fred C. Lee

[US PATENT: 10,396,684](#)

Issued: August 27, 2019

Abstract: Output current ripple is reduced in a three-level DC-DC power converter by connecting a plurality of phase legs in parallel between a source of input power and an output of the power converter and conducting power from the source of input power to the power converter output in an interleaved manner. The large current that results from such interleaved operation is reduced to acceptable levels, potentially less than the output current ripple of the power converter by providing inversely coupled inductors having a mutual inductance preferably greater than the inductor of the power converter in respective phase legs and in series in the circulating current path to avoid any need to increase the power converter inductance due to the circulating current. The inductor and inversely coupled inductors are preferably integrated into a single magnetic element of compact design.

VTIP 18-048

### *Soft-Switching Triangular Current Mode Control for Three Phase Two-Level Converters with Power Factor Control*

Nidhi Haryani, Rolando Burgos

[US PATENT: 10,381,921](#)

Issued: August 13, 2019

Abstract: Critical-mode soft-switching techniques for a power converter are described. In one example, a power converter includes a bidirectional converter electrically

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coupled between an alternating current (AC) power system and a direct current (DC) power system, where the bidirectional converter includes a number of phase legs. The power converter can also include a control system configured, during a portion of a line cycle of the AC power system, to clamp a first phase leg of the converter from switching and operate second and third phase legs of the converter independently in either critical conduction mode (CRM) or in discontinuous conduction mode (DCM).

### VTIP 16-057

#### *Omnidirectional Wireless Power Transfer System*

Junjie Feng, Qiang Li, Fred C. Lee, Minfan Fu

[US PATENT: 10,333,353](#)

Issued: June 25, 2019

Abstract: In one example, an omnidirectional wireless power transfer system includes high frequency power generator configured to generate a supply of high frequency oscillating power, a number of transmitter-side resonant tank circuits electrically coupled to the high frequency power generator, a receptacle including a number of coils arranged for omnidirectional power transfer to an electronic device placed in the receptacle, and a controller configured to activate individual ones of the transmitter-side resonant tank circuits to wirelessly transmit power to the electronic device through near-field resonant inductive coupling. In one example, the receptacle can be embodied as a bowl, and the controller can activate individual ones of the transmitter-side resonant tank circuits over time to generate an omnidirectional field distribution for wireless power transmission. In other aspects, various transmitter-side and receiver-side tank circuits for coupling independent resonance and ZVS operation are described.

### VTIP 15-064

#### *Current Mode Control DC-DC Converter with Single Step Load Transient Response*

Virginia Li, Pei-Hsin Liu, Qiang Li, Fred C. Lee

[US PATENT: 10,312,805](#)

Issued: June 4, 2019

Abstract: A power converter using constant on-time (COT) or ramp pulse modulation (RPM) control achieves more rapid resumption of steady-state operation after a step-up load transient by extending an on-time of a switching pulse by interrupting a ramp voltage waveform that is compared with a threshold that equals a threshold voltage at the termination of a switching pulse or increasing a voltage with which the ramp voltage is compared. These techniques are applied to both single-phase and multi-phase power converters.

### VTIP 17-004

*Cooler with Emi-Limiting Inductor*

By Khai Ngo, Chi-Ming Wang, Han Cui

[US PATENT: 10,290,587 \(Sponsored by Toyota, NOT IP SHARING\)](#)

Issued: May 14, 2019

Abstract: A power device package includes a dielectric substrate having an upper conductor layer and a lower conductor layer, a semiconductor die coupled to the upper conductor layer of the dielectric substrate via conductive adhesive, a cooler including a protruding hillock having a top surface and outer sides, the lower conductor layer of the dielectric substrate being coupled to the surface of the protruding hillock via an adhesive, and a magnetic material attached mateably around the protruding hillock. The magnetic material includes inner sides abutting the outer sides of the protruding hillock.

VTIP 17-016

*Critical-Mode-Based Soft-Switching Techniques for Three-Phase Bi-Directional AC/DC Converters*

Zhengrong Huang, Zhengyang Liu, Fred C. Lee, Qiang Li, Furong Xiao

[US PATENT: 10,291,109](#)

Issued: May 14, 2019

Abstract: Critical-mode soft-switching techniques for a power converter are described. In one example, a power converter includes a converter electrically coupled between an alternating current (AC) power system and a direct current (DC) power system, where the converter includes a number of phase legs. The power converter can also include a control system configured, during a portion of a whole line cycle of the AC power system, to clamp a first phase leg of the converter from switching and operate second and third phase legs of the converter independently in either critical conduction mode (CRM) or in discontinuous conduction mode (DCM).

VTIP 15-053

*Optimal Battery Current Waveform for Bidirectional PHEV Battery Charger*

Lingxiao Xue, Paolo Mattavelli, Dushan Boroyevich

[US PATENT: 10,250,053](#)

Issued: April 2, 2019

Abstract: The present invention provides a battery charger and battery charging method controlled with a charging waveform input of an AC-DC switching circuit to a DC link and a DC-DC stage converter for outputting a regulated DC voltage. The method determining the charging waveform comprising the steps of selecting a Pulse Width Modulation (PWM) zero-off charging waveform signal input to the AC-DC switching circuit and calculating a ripple power at the DC link based on the signal input power and output power of the regulated DC voltage output.

VTIP 16-115

*Multiphase Coupled and Integrated Inductors with Printed Circuit Board (PBC) Windings for Power Factor Correction (PFC) Converters*

Yuchen Yang, Mingkai Mu, Fred C. Lee, Qiang Li

[US PATENT: 10,217,559](#)

Issued: February 26, 2019

Abstract: A power factor correction (PFC) power converter, particularly of a multiphase totem-pole or other topology presenting a switching bridge that can potentially provide bi-directional power transfer control, reduces a nominal switching frequency and achieves zero voltage switching over an increased portion of a half line cycle by providing positive or inverse coupling of inductors in an inductor structure that can be formed of a multi-layer printed circuit board such that at least three different inductances are presented during each half line cycle period; allowing increased switching frequency and simplifying EMI filtering arrangements. Parasitic capacitances can be balanced with additional coupled windings to reduce differential mode and common mode noise. The PFC power converter is particularly applicable to provide bi-directional power control from an on-board battery charger in an electrically powered vehicle.

VTIP 17-059

*Method and Apparatus for Balancing Current and Power*

Yincan Mao, Chi-Ming Wang, Khai Ngo

[US PATENT: 10,187,050 \(Sponsored by TEMA, NOT IP SHARING\)](#)

Issued: January 22, 2019

Abstract: Aspects of the disclosure provide a power circuit that includes a first switch circuit in parallel with a second switch circuit. The first switch circuit and the second switch circuit are coupled to a first control node, a second control node, a first power node and a second power node via interconnections. The power circuit receives a control signal between the first control node and the second control node to control a current flowing from the first power node to the second power node through the first switch circuit and the second switch circuit. At least one of a first source terminal of the first switch circuit and a second source terminal of the second switch circuit is coupled to the second control node with a resistive element having a specific resistance.

VTIP 16-094

*Circulating Current Injection Control*

Jun Wang, Rolando Burgos, Dushan Boroyevich

[US PATENT: 10,153,712](#)



## CPES Patent Portfolio

Issued: December 11, 2018

Abstract: In one example, a power converter includes a modular multilevel converter (MMC) electrically coupled between a first power system and a second power system. The MMC includes an arrangement of switching submodules, and the switching submodules include an arrangement of switching power transistors and capacitors. The MMC also includes a controller configured to inject a common mode frequency signal into a circulating current control loop. The circulating current control loop is relied upon to reduce at least one low frequency component in power used for charging the capacitors in the switching submodules. By injecting the common mode frequency signal into the circulating current control loop, the switching submodules can be switched at higher frequencies, the capacitances of the capacitors in the MMC can be reduced, and the power density of the MMC can be increased.

### VTIP 16-030

#### *Parallel Devices Having Balanced Switching Current and Power*

Yincan Mao, Chi-Ming Wang, Zichen Miao, Khai Ngo

[US PATENT: 10,116,303 \(Sponsored by TEMA, NOT IP SHARING\)](#)

Issued: October 30, 2018

Abstract: A power circuit includes a power source for providing electrical power and two driving transistors being disposed in parallel and receiving electrical power from the power source. Each of the two driving transistors includes a gate terminal, a source connection, and a kelvin source connection. The power circuit also includes a control voltage source having a first terminal and a second terminal. The control voltage source provides a control signal to the two driving transistors for determining driving currents through the two driving transistors. The first terminal is connected to the gate terminals of the two driving transistors, and the second terminal is connected to the kelvin source connections of the two driving transistors. The kelvin source connections of the two driving transistors are inductively coupled.

### VTIP 14-101

#### *Transient Performance Improvement for Constant On-Time Power Converters*

Syed Bari, Fred C. Lee, Qiang Li, Pei-Hsin Liu

[US PATENT: 10,110,122](#)

Issued: October 23, 2018

Abstract: Response of a variable frequency switching constant on-time or adaptive on-time controlled power converter to a large step-up or step-down change in load is improved with a simple circuit that detects magnitude and polarity of a change in output voltage and initiates, extends or terminates conduction of power pulses from an input source through said power converter. Both the amplitude and duration of undershoot or overshoot of the transient response are reduced or, alternatively, the

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capacitance of an output filter may be significantly reduced and still provide comparable transient performance. The fast adaptive on-time control is applicable to multi-phase power converters using phase managers or one or more phase-locked loops for interleaving of power pulses.

### VTIP 14-144 (CIP to 13-169)

#### *Low Profile Coupled Inductor Substrate with Transient Speed Improvement*

Yipeng Su, Dongbin Hou, Fred C. Lee, Qiang Li

[US PATENT: 10,109,404](#)

Issued: October 23, 2018

Abstract: A low profile inductor structure suitable for use in a high power density power converter has one or more windings formed by vias through a thin, generally planar body of magnetic material forming the inductor core and conductive cladding on the body of magnetic material or material covering the magnetic material body. Variation of inductance with load current and other operational or environmental parameters is reduced to any desired degree by forming a slot that removes all or a portion of the magnetic material between the locations of the vias.

### VTIP 15-071 (includes 15-070)

#### *Multi-Step Simplified Optimal Trajectory Control (SOTC) Based on Only $V_o$ and $I_{load}$*

Chao Fei, Fred C. Lee, Weiyi Feng, Qiang Li

[US PATENT: 10,075,083](#)

Issued: September 11, 2018

Abstract: A resonant power converter is disclosed with a driving circuit generating a switching signal connecting power to a resonant tank circuit, with a voltage monitoring circuit measuring a voltage output and a load current. A micro-controller is operable with a control circuit for multiple step sampling with the switching signal at a switching frequency to settle the resonant circuit determined from the voltage output and load current. A fast load transient response at a high frequency with the resonant circuit provides the multiple step sampling to ensure enough time for micro-controller to calculate. Optimal trajectory control facilitates a burst mode of high frequency with the resonant circuit using adaptive multiple step sampling for an on-time to extend the burst operation range. A soft start-up process uses the micro-controller processing in multiple stages.

### VTIP 17-072

#### *Semiconductor Module Arrangement*

Christina DiMarino, Dushan Boroyevich, Rolando Burgos, Mark Johnson

[US PATENT: 10,032,732](#)

Issued: July 24, 2018

## CPES Patent Portfolio

**Abstract:** In a switching module structure that includes a low-impedance path to ground, such as a parasitic capacitance of an insulating substrate, a further insulating substrate presenting a parasitic capacitance placed in series with the low impedance current path and a connection of a conductive layer to input voltage rails using a single decoupling capacitor or, preferably, a midpoint of the voltage rails formed by a series connection of decoupling capacitors maintains a large portion of common mode (CM) currents which are due to high dV/dt slew rates of SiC and GaN transistors within the switching module.

### VTIP 14-066

#### *Hybrid Interleaving Structure with Adaptive Phase locked Loop for Variable Frequency Controlled Switching Converter*

Pei-Hsin Liu, Qiang Li, Fred C. Lee

**US PATENT:** [10,013,007](#)

Issued: July 3, 2018

**Abstract:** In a multi-phase power converter using a phase-locked loop (PLL) arrangement for interleaving of pulse frequency modulated (PFM) pulses of the respective phases, improved transient response, improved stability of high bandwidth output voltage feedback loop, guaranteed stability of the PLL loop and avoidance of jittering and phase cancellation issues are achieved by anchoring the bandwidth at the frequency of peak phase margin. This methodology is applicable to multi-phase power converters of any number of phases and any known or foreseeable topology for individual phases and is not only applicable to power converters operating under constant on-time control, but is extendable to ramp pulse modulation (RPM) control and hysteresis control. Interleaving of pulses from all phases is simplified through use of phase managers with a reduced number of PLLS using hybrid interleaving arrangements that do not exhibit jittering even when ripple is completely canceled.

### VTIP 16-005

#### *Power Switch Drivers with Equalizers for Paralleled Switches*

Khai D.T. Ngo, Lujie Zhang, Zichen Miao

**US PATENT:** [9,998,111](#)

Issued: June 12, 2018

**Abstract:** Capacitors connected between gate terminals of a plurality of parallel-connected power transistors are charged and discharged in each switching cycle to provide a plurality of power transistor control waveforms from a single gate driver waveform that equalize power losses/temperatures or steady-state currents among the plurality of power transistors. The capacitors are charged to different voltages by diverting current from one transistor driver by disabling another power transistor

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driver at different respective times in response to measured transient or steady state current or temperature or other operational parameter.

### VTIP 14-053 (combined with 14-147)

#### *Power-Cell Switching-Cycle Capacitor Voltage Control for Modular Multi-Level Converters*

Jun Wang, Rolando Burgos, Dushan Boroyevich, Bo Wen

[US PATENT: 9,966,874](#)

Issued: May 8, 2018

Abstract: In a modular multi-level power converter, additional switching states are interleaved between main switching states that control output voltage or waveform. The additional switching states provide current from a DC-link to charge capacitors in respective modules or cells to an offset voltage from which the capacitor voltages are controlled toward a reference voltage during each switching cycle rather than being allowed to build up over a period of an output waveform of variable line frequency, possibly including zero frequency. Since the switching cycle is much shorter than the duration of a line frequency cycle and the capacitor voltages are balanced during each switching cycle, output voltage ripple can be limited as desired with a capacitor of much smaller value and size than would otherwise be required.

### VTIP 16-110

#### *Method and Apparatus for Current/Power Balancing*

Chi-ming Wang, Yincan Mao, Zichen Miao, Khai Ngo

[US PATENT: 9,923,560 \(Sponsored by TEMA, NOT IP SHARING\)](#)

Issued: March 20, 2018

Abstract: Aspects of the disclosure provide a system having a power circuit. The power circuit includes a first switch circuit having at least a first transistor and a second switch circuit having at least a second transistor. Further, the power circuit includes first interconnections configured to couple the first switch circuit to driving nodes, a source node and a drain node of the power circuit, and second interconnection configured to couple the second switch circuit in parallel to the first switch circuit to the driving nodes, the source node and the drain node of the power circuit. A polarity of unbalance in the first interconnections and the second interconnections dominates a polarity of current unbalance in the first switch circuit and the second switch circuit.

### VTIP 12-044

#### *Energy Storage for Power Factor Correction in Battery Charger for Electric-Powered Vehicles*

Khai Doan The Ngo, Hui Wang

[US PATENT: 9,914,362](#)

## CPES Patent Portfolio

Issued: March 13, 2018

Abstract: Switches of a switching circuit used to control operation of an electric motor such as in an electrically powered vehicle connect respective windings of the electric motor as a single phase inductor during battery charging. The inductor can then store inherent low frequency, second order ripple power and return that power to a load presented by a battery during battery charging to deliver substantially constant current. Storage of ripple power in the inductor allows the capacitance value, size, weight and cost of a filter capacitor of a power factor correction circuit providing input power to a battery charger to be reduced by an order of magnitude or more. Direction of current flow through the inductor is periodically reversed to avoid magnetizing the motor.

VTIP 15-069

### *Universal System Structure for Low Power Adapters*

Fred C. Lee, Xiucheng Huang, Qiang Li

[US PATENT: 9,847,710](#)

Issued: December 19, 2017

Abstract: A two-stage power converter architecture including an isolation transformer and rectification of the isolation transformer output by an LLC resonant circuit and methodology for operating the same feeds an output voltage back to a circuit for generating waveforms for controlling a totem pole circuit to provide output voltage regulation as well as rectification of AC input voltage. The circuit for controlling the totem pole circuit may also be responsive to the AC input power waveform to provide power factor correction (PFC), in which case, the feedback signal provides additional pulse width modulation of the PFC signals. Bus capacitor size may also be reduced by injecting harmonics of the AC input waveform into the feedback signal which also serves to substantially maintain efficiency of the (preferably LLC) resonant second stage.

VTIP 15-068

### *Circuit and Method for Driving Synchronous Rectifiers for High-Frequency Flyback Converters*

Xiucheng Huang, Fred Lee, Qiang Li

[US PATENT: 9,812,978](#)

Issued: November 7, 2017

Abstract: A voltage waveform similar to a waveform of a magnetizing current of an isolation transformer and immune to high frequency oscillatory resonant behavior is developed across a capacitor of a series resistor and capacitor connection connected in parallel with a synchronous rectifier. A simple logic circuit produces a waveform for controlling the synchronous rectifier which is not subject to significant turn on delay or

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early turn off caused by oscillatory resonances among parasitic inductances and capacitances. Improved timing accuracy of a synchronous converter provides improved power converter accuracy, particularly for flyback converters which are commonly used in converters for supplying power to offline electrical devices but are subject to oscillatory resonant behaviors that cannot be adequately damped at switching frequencies sufficiently high to support miniaturization of adapters.

### VTIP 14-065

#### *Avoiding Internal Switching Loss in Soft Switching Cascode Structure Device*

Xiucheng Huang, Weijing Du, Qiang Li, Fred C. Lee

[US PATENT: 9,735,238](#)

Issued: August 15, 2017

Abstract: In a cascode switching device, avalanche breakdown of a control transistor and loss of soft switching or zero voltage switching in a high voltage normally-on depletion mode transistor having a negative switching threshold voltage and the corresponding losses are avoided by providing additional capacitance in parallel with a parallel connection of drain-source parasitic capacitance of the control transistor and gate-source parasitic capacitance of the high voltage, normally-on transistor to form a capacitive voltage divider with the drain-source parasitic capacitance of the high voltage, normally-on transistor such that the avalanche breakdown voltage of the control transistor cannot be reached. The increased capacitance also assures that the drain source parasitic capacitance of the high voltage, normally-on transistor is fully discharged before internal turn-on can occur.

### VTIP 12-122

#### *Maximum Power Point Tracking for Solar Panels*

Xinke Wu, Zijian Wang, Fred C. Lee, Feng Wang

[US PATENT: 9,685,790](#)

Issued: June 20, 2017

Abstract: Approximately one-half of the loss of delivered power from a solar panel having photovoltaic (PV) cells connected in series to form sub-panels due to shading is recovered at low hardware cost by connecting sub-panels in series and providing maximum power point tracking control in common for the series connected sub-panels such that the respective sub-panels produce equal voltages even in the presence of shading of a portion of one or more sub-panels. By doing so, the input voltage of respective power converters which control the voltage at which each sub-panel is operated can be placed close to the maximum power point of each sub-panel regardless of shading and maximum total power harvested even though the respective sub-panels are not operated at optimum voltages.

VTIP 12-130

*External Ramp Autotuning for Current Mode Control of Switching Converter*

Pei-Hsin Liu, Fred C. Lee, Yingyi Yan, Paolo Mattavelli

[US PATENT: 9,678,521](#)

Issued: June 13, 2017

Abstract: Peak current, valley current or average current mode controlled power converters in either digital or analog implementations obtain a stabilized feedback loop and allow high system bandwidth design by use of an external ramp generator using a slope computation equation or design parameters based on fixing the quality factor of a double pole at one-half of the switching frequency at a desired value. The slope of the external ramp waveform is tuned automatically with knowledge of the slope change in the waveform of inductor current of a power converter derived by differentiating a waveform in the current feedback loop. This autotuning of the external ramp generator provides immunity of quality factor change under variations of duty cycle, component values or topological change of the power converter.

VTIP 16-061

*Method and Apparatus to Improve Power Device Reliability*

Yincan Mao, Zichen Miao, Khai Ngo, Chi-Ming Wang

[US PATENT: 9,660,643 \(Sponsored by TEMA, NOT IP SHARING\)](#)

Issued: May 23, 2017

Abstract: Aspects of the disclosure provide a power device that includes an upper power module and a lower power module. The upper power module and the lower power module are coupled in series between two supply voltages, and are respectively controlled by a first control signal and a second control signal. Interconnections of the power device are inductively coupled to prevent reliability issues, such as crosstalk, self turn on, self sustained oscillation, and the like.

VTIP 12-024

*Anti-Islanding Detection For Three-Phased Distributed Generation*

Dong Dong, Dushan Boroyevich, Paolo Mattavelli

[US PATENT: 9,634,673](#)

Issued: April 25, 2017

Abstract: Wobbling the operating frequency of a phase-locked loop (PLL), preferably by adding a periodic variation in feedback gain or delay in reference signal phase allows the avoidance of any non-detection zone that might occur due to exact synchronization of the phase locked loop operating frequency with a reference signal. If the change in PLL operating frequency is periodic, it can be made of adequate speed variation to accommodate and time requirement for islanding detection or the like when a reference signal being tracked by the PLL is lost. Such wobbling of the PLL

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operating frequency is preferably achieved by addition a periodic variable gain in a feedback loop and/or adding a periodically varying phase delay in a reference signal and/or PLL output.

### VTIP 13-166

#### *System and Method for Impedance Measurement Using Chirp Signal Injection*

Zhiyu Shen, Marko Jaksic, Paolo Mattavelli, Dushan Boroyevich, Jacob Verhulst, Mohamed Belkhat

[US PATENT: 9,618,555 \(Sponsored by Huntington Ingalls - Newport News Shipbuilding, NOT IP SHARING\)](#)

Issued: April 11, 2017

Abstract: A method for impedance measurement using chirp signal injection is provided. The method includes injecting at least one chirp signal into the three-phase AC system, and collecting at least one response to the at least one chirp signal. The method further includes transferring the at least one response from abc coordinates to dq coordinates. At least one impedance is calculated based on the at least one response to the at least one chirp signal.

### VTIP 13-085

#### *V<sup>2</sup> Power Converter Control With Capacitor Current Ramp Compensation*

Yingyi Yan, Pei-Hsin Liu, Fred C. Lee

[US PATENT: 9,601,997](#)

Issued: March 21, 2017

Abstract: Operation of a switching power converter having an output capacitor having a small equivalent series resistance (ESR) is stabilized and jitter reduced by sensing capacitor current with gain and combining the resulting signal with the output voltage signal to provide a feedback signal to control switching of the power converter. capacitor current can be sensed without interfering with operation of the filter capacitor by providing a branch circuit having a time constant matched to the output or filter capacitor but an arbitrarily high impedance so as to be effectively lossless. The gain provided in the capacitor current signal can be tuned to provide optimally short settling time after load transients; generally within one switching cycle. Matching of time constants and/or tuning of gain can be performed automatically.

### VTIP 13-032

#### *Method for Reducing or Eliminating Conducted Common Mode Noise in a Transformer*

Yuchen Yang, Daocheng Huang, Qiang Li, Fred C. Lee

[US PATENT: 9,589,718](#)

Issued: March 7, 2017



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Abstract: At least one shield member interposed between primary and secondary windings of a transformer and connected to the primary and/or secondary windings forms a distributed parasitic capacitance between the shield member and either the winding to which it is not connected or another shield member connected to that winding. Connections are made to the respective transformer windings such that the voltage distributions thus developed cause complementary common mode noise to be conducted in opposite directions in respective portions of the parasitic capacitance such that net common mode current can be made arbitrarily small without requiring that both sides of the distributed parasitic capacitance have complementary or equal voltage distributions. Such complementary common mode currents can be achieved by dividing opposing shield members or developing a voltage distribution in a single shield member in accordance with Faraday's Law.

### VTIP 16-047

#### *Method and Apparatus for Current/Power Balancing*

Yincan Mao, Zichen Miao, Khai Ngo, Chi-Ming Wang

[US PATENT: 9,584,116 \(Sponsored by TEMA, NOT IP SHARING\)](#)

Issued: February 28, 2017

Abstract: Aspects of the disclosure provide a power circuit that includes a first switch circuit in parallel with a second switch circuit. The first switch circuit and the second switch circuit are coupled to a first driving node, a second driving node, a source node and a drain node via interconnections. The power circuit receives a control signal between the first driving node and the second driving node to control a current flowing from the drain node to the source node through the first switch circuit and the second switch circuit. In the power circuit, a first interconnection and a second interconnection of the interconnections are inductively coupled to balance the current flowing through the first switch circuit and the second switch circuit.

### VTIP 13-169

#### *High Frequency Integrated Point-of-Load Power Converter With Embedded Inductor Substrate*

Yipeng Su, Qiang Li, Fred C. Lee, Wenli Zhang

[US PATENT: 9,564,264](#)

Issued: February 7, 2017

Abstract: A low profile power converter structure is provide wherein volume is reduced and power density is increased to approach 1 KW/in<sup>3</sup> by at least one of forming an inductor as a body of magnetic material embedded in a substrate formed by a plurality of printed circuit board (PCB) lamina and forming inductor windings of PCB cladding and vias which may be of any desired number of turns and may include inversely coupled windings and which provide a lateral flux path, forming the body of

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magnetic material from high aspect ratio flakes of magnetic material which are aligned with the inductor magnetic field in an insulating organic binder and hot-pressed and providing a four-layer architecture comprising two layers of PCB lamina including the embedded body of magnetic material, a shield layer and an additional layer of PCB lamina, including cladding for supporting and connecting a switching circuit, a capacitor and the inductor.

### VTIP 13-167

#### *System and Method for Impedance Measurement Using Series and Shunt Injection*

Jacob Verhulst, Mohamed Belkhat, Zhiyu Shen, Marko Jaksic, Paolo Mattavelli, Dushan Boroyevich

[US PATENT: 9,562,939 \(Sponsored by Huntington Ingalls - Newport News Shipbuilding, NOT IP SHARING\)](#)

Issued: February 7, 2017

Abstract: A method for impedance measurement in a three-phase AC system is provided. The method includes injecting a shunt perturbation signal into the three-phase AC system and collecting a response to the shunt perturbation signal, and injecting a series perturbation signal into the three-phase AC system and collecting a response to the series perturbation signal. The response to the shunt perturbation signal and the response to the series perturbation signal are then transferred from abc coordinate to dq coordinates. At least one impedance of the three-phase AC system is calculated based on the response to the shunt perturbation signal and the response to the series perturbation signal.

### VTIP 14-097

#### *Two-Stage Multichannel LED Driver with CLL Resonant Circuit*

Xuebing Chen, Daocheng Huang, Qiang Li, Fred C. Lee

[US PATENT: 9,544,956 \(Sponsored by Panasonic, NOT IP SHARING\)](#)

Issued: January 10, 2017

Abstract: In a two-stage power converter providing voltage regulation in a first stage, zero voltage switching (ZVS) is provided in switches in an unregulated, constant frequency second stage of a two-stage power converter by an inductor of a CLL resonant circuit connected in parallel with both a series connection of an external inductor and a primary winding of one or more transformers connected in series and an output of the switching circuit so that the output capacitances of the switches can be charged and discharged, respectively, by current in the parallel-connected inductor and independently of current in the magnetizing inductance of the transformer. Therefore, the magnetizing inductance of the transformer can be made sufficiently large to balance currents delivered to respective loads as is particularly

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desirable for driving a plurality of unbalanced LED strings independently of the value of the parallel-connected inductor which is desirably small.

### VTIP 16-008

#### *Method and Apparatus for Driving a Power Device*

Jongwon Shin, Chi-Ming Wang, Khai Ngo

[US PATENT: 9,531,378 \(Sponsored by Toyota, NOT IP SHARING\)](#)

Issued: December 27, 2016

Abstract: Aspects of the disclosure provide a circuit for driving a power switch. The circuit includes a first circuit configured to provide a charging current to charge a control terminal of the power switch, a second circuit configured to provide a discharging current to discharge the control terminal of the power switch, and a control circuit configured to provide control signals to the first circuit and the second circuit to activate/deactivate the first circuit and the second circuit. At least one of the charging current and the discharging current ramps from a first level to a second level at a rate.

### VTIP 13-008

#### *Electrical Power System Stability Optimization System*

Sheau-Wei Fu\*, Kamiar Karimi\*, Marko Jaksic, Bo Zhou, Bo Wen, Paolo Mattavelli, Dushan Boroyevich

[US PATENT: 9,471,731 \(Sponsored by Boeing, NOT IP SHARING\)](#)

Issued: October 18, 2016

Abstract: A method and apparatus for electrical power system stability optimization. An electrical power system comprising source elements and load elements is simulated to generate impedance data, wherein the impedance data identifies an impedance of the electrical power system. A stability profile of the electrical power system is characterized as a function of the impedance data, wherein the stability profile identifies the source elements and load elements to control power generation by the electrical power system to optimize stability of the electrical power system.

### VTIP 13-014

#### *$\hat{P}$ Average Current Mode (ACM) Control for Switching Power Converters*

Yingyi Yan, Fred C. Lee, Paolo Mattavelli

[US PATENT: 9,343,964](#)

Issued: May 17, 2016

Abstract: Providing a fast current sensor direct feedback path to a modulator for controlling switching of a switched power converter in addition to an integrating feedback path which monitors average current for control of a modulator provides fast dynamic response consistent with system stability and average current mode

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control. Feedback of output voltage for voltage regulation can be combined with current information in the integrating feedback path to limit bandwidth of the voltage feedback signal.

### VTIP 12-131

#### *Optimal Trajectory Control for LLC Resonant Converter for Soft Start-Up*

Weiyi Feng, Fred C. Lee

[US PATENT: 9,318,946](#)

Issued: April 19, 2016

Abstract: By setting switching instants of a switching circuit of a resonant power converter based on current in a resonant circuit reaching a current limit of a current limitation band, soft start-up of the power converter can be achieved to avoid or limit electrical stress with full control over a trade-off between time required to settle to a full load steady-state mode of operation and the amount of electrical stress permitted while soft start up switching frequency is automatically optimized.

### VTIP 12-152

#### *Optimal Trajectory Control for LLC Resonant Converter for LED PWM Dimming*

Weiyi Feng, Fred C. Lee, Shu Ji

[US PATENT: 9,276,480](#)

Issued: March 1, 2016

Abstract: Pulse width modulation is provided for controlling a resonant power converter, particularly for dimming of light emitting diode arrays without loss of efficiency. Dynamic oscillation due to the beginning of a pulse width modulated pulse burst is limited by shortening of the first and/or last pulse of a pulse burst such that the first pulse of a subsequent pulse burst close to or to connect with a full load steady-state voltage/current trajectory of the power converter. Pulse shortening made be made substantially exact to virtually eliminate dynamic oscillation but substantial reduction in dynamic oscillation is provided if inexact or even performed randomly.

### VTIP 12-010

#### *Algorithm and Implementation System for Measuring Impedance in the D-Q Domain*

Gerald Francis, Rolando Burgos, Dushan Boroyevich, Fred Wang, Zhiyu Shen, Paolo Mattevelli, Kamiar Karimi, Sheau-Wei Johnny Fu

[US PATENT: 9,140,731](#)

Issued: September 22, 2015

Abstract: A controller and infrastructure for an impedance analyzer measures responses to perturbations to respective phases of a multi-phase system at an interface between stages thereof (which may be considered as a source and load in regard to each other), such as a multi-phase electrical power system, to determine a

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transfer function for each phase of the multi-phase system from which the impedance of each of the source and load can be calculated, particularly for assessing the stability of the multi-phase system.

### VTIP 12-009

#### *Method of Evaluating and Ensuring Stability of AC/DC Power Systems*

Rolando Burgos, Dushan Boroyevich, Fred Wang, Kamiar Karimi

[US PATENT: 9,136,773](#)

Issued: September 15, 2015

Abstract: Approximating loci of eigenvalues or characteristic gains of a return ratio matrix of a model of a multi-phase power converter circuit by the loci of the d-d and q-q elements of said synchronous frame of reference applied to said model, allows determination and assessment of stability of the circuit or forbidden operational parameters of the combination of an AC power source and a power converter at an interface thereof by application of a standard Nyquist stability criterion.

### VTIP 11-075

#### *Two-Stage Bi-Directional Single-Phase Converter with DC-Link Capacitor Reduction*

Dong Dong, Dushan Boroyevich, Ruxi Wang, Fred Wang

[US PATENT: 9,071,141](#)

Issued: June 30, 2015

Abstract: DC link capacitance in a bi-directional AC/DC power converter using a full-bridge or H-bridge switching circuit can be greatly reduced and the power density of the power converter correspondingly increased by inclusion of a bi-directional synchronous rectifier (SR) DC/DC converter as a second stage of the power converter and controlling the second stage with a control loop having a transfer function common to both buck and boost modes of operation of the bi-directional SR DC/DC converter and a resonant transfer function to increase gain at the ripple voltage frequency (twice the AC line frequency) to control the duty cycle of the switches of the bi-directional SR DC/DC stage and controlling the duty cycle of the switches of the full-bridge or H-bridge switching circuit using a control loop including a notch filter at the ripple voltage frequency.

### VTIP 11-113

#### *DC-Side Leakage Current Reduction for Single-Phase Full-bridge Power Converter/Inverter*

Dong Dong, Fang Luo, Dushan Boroyevich, Paolo Mattavelli

[US PATENT: 9,048,756](#)

Issued: June 2, 2015

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Abstract: Leakage current through stray or parasitic capacitance (which is particularly large in devices such as photovoltaic cell arrays and which are damaged by such leakage currents) due to common mode switching noise in a full bridge single phase power converter is reduced at high frequencies by magnetically coupling the two phase legs on the AC side of the power converter and connecting mid points of the AC and DC sides of the power converter and is reduced at low frequencies by use of a feedback arrangement that modifies sinusoidal modulation of the switches of the full bridge converter to function as an active filter. The magnetic coupling for the two phase legs is designed in a simple manner to avoid saturation based on volt-second considerations.

### VTIP 13-046

#### *Multi-Channel Two-Stage Controllable Constant Current Source and Illumination Source*

Weiyei Feng, Fred C. Lee

[US PATENT: 9,000,673](#)

Issued: April 7, 2015

Abstract: A multi-channel constant current source particularly suitable for driving an array of light-emitting diodes as an illumination apparatus provides a power source stage voltage regulator for providing a variable voltage using pulse width modulation as an input to a plurality of constant current driver channels to regulate the constant current provided. Pulse width modulation thus allows both the power source stage and the constant current driver operating frequencies to be decoupled and individually optimized to maintain efficiency while emulating dimming effects of, for example, incandescent bulbs, over a full range of light output flux. Pulse width modulation can also be employed in the constant current channel drivers to avoid chromaticity shift during dimming.

### VTIP 13-025

#### *Anti-Islanding Protection in Three-Phase Converters Using Grid Synchronization Small-Signal Stability*

Dong Dong, Dushan Boroyevich, Paolo Mattavelli, Bo Wen

[US PATENT: 8,957,666](#)

Issued: February 17, 2015

Abstract: A small signal feedback loop or feed-forward loop having gain provides substantially unconditional instability in a phase locked loop when a reference phase signal is lost. The small signal feedback or feed-forward also modifies phase locked loop bandwidth when the reference phase signal is lost to increase rapidity of response to loss of reference phase signal while maintaining insensitivity to reference voltage amplitude change while the reference phase signal is present. The

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performance thus achieved is particularly suitable for rapid condition detection response and control of a grid connected power converter under islanding conditions.

### VTIP 11-074

#### *Three-Level Active Neutral-Point-Clamped Zero-Voltage Switching Converter*

Jin Li, Dushan Boroyevich, Jinjun Liu

[US PATENT: 8,929,114](#)

Issued: January 6, 2015

Abstract: A main circuit of a three-level active neutral point clamped voltage source converter having a pair of additional main switches provides two paths between an output node and a neutral point in which one of the paths involves only switches of an inner pair of switches that are operated at a high frequency. An auxiliary circuit operating at a high frequency for only a brief period during each high frequency switching cycle selects the path involving only the inner switches and provides operation with zero voltage switching and avoids reverse recovery of diodes connected antiparallel with the main and additional main switches. Accordingly, turn-on switching losses in the main switches is avoided and the voltage source converter can be operated at increased frequency to allow reduction in size of magnetic components and full potential power transfer to be achieved.

### VTIP 11-130

#### *Multilayer Packaged Semiconductor Device and Method of Packaging*

Kaushik Rajashekara, Ruxi Wang, Zheng Chen, Dushan Boroyevich

[US PATENT: 8,829,692 \(Sponsored by Rolls-Royce, NOT IP SHARING\)](#)

Issued: September 9, 2014

Abstract: One embodiment is a packaged device having multiple layers. Another embodiment is a method of forming a packaged device having multiple layers. Conductive layers and insulating layers can be formed with openings exposing semiconductor devices. The semiconductor devices can be wire-bonded to the conductive layers. In some embodiments, parasitic effects and a relative footprint of the packaged device can be reduced.

### VTIP 10-030/10-031

#### *Use of PLL Stability for Islanding Detection*

Timothy Thacker, Dushan Boroyevich, Fred Wang, Rolando Burgos

[US PATENT: 8,823,416](#)

Issued: September 2, 2014

Abstract: A phase detector for a phase-locked loop includes a phase detector that is configured to become unstable, oscillate and drift rapidly in frequency in a predictable manner when a reference frequency signal is not available. When applied, for

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example, to a power converter connected to a power distribution grid, the predictable oscillatory and rapid frequency drift behavior when the phase detector is unstable allows very rapid and reliable detection of disconnection from the grid, referred to as islanding.

### VTIP 11-049

#### *High Frequency Loss Measurement Apparatus and Methods for Inductors and Transformers*

Mingkai Mu, Fred C. Lee

[US PATENT: 8,823,370](#)

Issued: September 2, 2014

Abstract: Core loss in an inductor is measured with reduced sensitivity to phase measurement error by connecting a reactive component to resonate with the inductor and thus cancel a portion of the reactive voltage on the inductor; reducing the phase difference between the inductor voltage and current and making the observed power more resistive. The reactive component may be a capacitor for sinusoidal excitation or an inductance such as an air core transformer for arbitrary excitation.\_.

### VTIP 11-002

#### *Pulse-Width-Modulated Resonant Power Conversion*

Khai D.T. Ngo, Xiao Cao, Yin Wang

[US PATENT: 8,811,039](#)

Issued: August 19, 2014

Abstract: A power converter including a resonant circuit is controlled by pulse width modulation (PWM) of a switching circuit to control current in the resonant circuit near the frequency of the resonant circuit (a null-immittance criterion) in order to control current and voltage at the output of the resonant circuit. Further control of voltage can be performed by PWM of a switching circuit at the output of the resonant circuit such that centers of the duty cycles of respective switches for the output of the resonant circuit are substantially synchronized and substantially symmetrical about centers of said duty cycles of respective switches at the input of the resonant circuit. Thus, operation of the converter is substantially simplified by using only PWM, a wide range of input and output voltages can be achieved and the converter circuit can be configured for bi-directional power transfer.

### VTIP 09-124

#### *Adaptive On-Time Control for Power Factor Correction Stage Light Load Efficiency*

Qian Li, Fred C. Lee, Ming Xu, Chuanyun Wang

[US PATENT: 8,803,489](#)

Issued: August 12, 2014



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Abstract: Light load efficiency of a power factor correction circuit is improved by adaptive on-time control and providing for selection between a continuous conduction mode and a discontinuous conduction mode wherein the discontinuous conduction mode increases time between switching pulses controlling connection of a cyclically varying voltage to a filter/inductor that delivers a desired DC voltage and thus can greatly reduce the switching frequency at light loads where switching frequency related losses dominate efficiency. The mode for controlling switching is preferably selected for each switching pulse within a half cycle of the cyclically varying input voltage. A multi-phase embodiment allows cancellation of EMI noise at harmonics of the switching frequency and adaptive change of phase angle allows for cancellation of dominant higher order harmonics as switching frequency is reduced.

VTIP 09-096

### *Multi-Phase EMI Noise Separator*

Shuo Wang, Fred C. Lee

[US PATENT: 8,698,579](#)

Issued: April 15, 2014

Abstract: Common mode (CM) and differential mode (DM) components of multi-phase conducted electromagnetic interference (EMI) noise emanating from electronic circuits such as power converters/inverters are separated by respective coupled inductors connected to each phase of three or more phases and which are coupled to each other differently for CM and DM noise of the respective phases. The inductors of the DM separation unit are coupled such that a substantially ideal zero impedance is presented to DM noise while a high impedance is presented to CM noise. Conversely, the inductors of the CM separation unit are coupled such that a substantially ideal zero impedance is presented to CM noise while a high impedance is presented to DM noise.

VTIP 10-095

### *Multi-Channel Constant Current Source and Illumination Source*

Shu Ji, Haoran Wu, Fred C. Lee

[US PATENT: 8,598,807](#)

Issued: December 3, 2013

Abstract: A multi-channel circuit having respective channels powered through transformers having primary windings connected in series allows substantially equal constant currents to be provided through all channels by cross-regulation while only a single channel need be monitored and controlled. The variation in current between channels is generally small and largely insensitive to imbalances between voltages on loads due, for example, to different numbers of LEDs in series connected strings in illumination devices and can be further reduced by inverse coupling between

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inductors in respective channels. Efficiency is improved through reduction in the number of stages of the constant current source since the respective channels provided both DC-to-DC conversion and constant current regulation.

### VTIP 10-094

#### *Digital Hybrid $V^2$ Control for Buck Converters*

Kuang-Yao (Brian) Cheng, Feng Yu, Paolo Mattavelli, Fred C. Lee

[US PATENT: 8,575,911](#)

Issued: November 5, 2013

Abstract: Stabilization of a switching voltage regulator employing  $V^2$  control against ripple oscillation instability when the equivalent series resistance (ESR) of an output capacitor is small is provided by providing both an external ramp and an internal ramp (only the latter of which requires an approximation of inductor current) in the control feedback path, preferably including both inner and outer feedback loops. Approximation of inductor current using such an arrangement is non-critical and may be estimated based on power input voltage. Drift of a circuit providing such an inductor current estimation is preferably avoided by adjusting control duty cycle or slew rate of the positive-going ramp portion of the estimated inductor current triangular waveform.

### VTIP 10-003

#### *Electrical Power System with High-Density Pulse Width Modulated (PWM) Rectifier*

Ruxi Wang, Fred Wang, Rolando Burgos, Dushan Boroyevich, Kaushik Rajashekara, Stephen A. Long

[US PATENT: 8,570,774 \(Sponsored by Rolls-Royce, NOT IP SHARING\)](#)

Issued: October 29, 2013

Abstract: An electrical power system includes an alternating current (AC) power source configured to output an AC signal, a single phase pulse-width modulated (PWM) rectifier coupled to the AC power source and to an electrical load; a DC link capacitor coupled in parallel to the load and the PWM rectifier; and an active ripple energy storage circuit. The active ripple energy storage circuit has a first terminal, a second terminal and a third terminal, the active ripple energy storage circuit being coupled in parallel to the electrical load, the PWM rectifier and the DC link capacitor via the first terminal and the second terminal, the third terminal being coupled to the second terminal, the active ripple energy storage circuit being configured to selectively absorb and discharge at least part of the ripple energy.

### VTIP 05-052

#### *Method of Manufacture of a Variable Inductance Inductor*

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Michele H. Lim, J.D. van Wyk

[US PATENT: 8,549,731](#)

Issued: October 8, 2013

Abstract: Ceramic inductors are made from stacked sheets of co-fired ceramic. At least one of the ceramic sheets has a slot with a conductor disposed in the slot. The conductor has a thickness equal to a thickness of the ceramic sheet containing the slot. The conductor has large thickness (compared to prior art co-fired ceramic inductors) and therefore can carry large currents. The present ceramic inductor can be used in power electronics applications due to the ability to carry large currents. The present ceramic inductor preferably has an inductance that decreases with increasing current. A decreasing inductance characteristic tends to increase energy efficiency in a voltage regulator when the inductor is used as an output inductor. Specifically, the variable inductance tends to substantially increase energy efficiency at low current loads without adversely affecting efficiency at high loads.

VTIP 08-036

*Switching Capacitor-PWM Power Converter*

Ming Xu, Ke Jin, Fred C. Lee

[US PATENT: 8,331,110](#)

Issued: December 11, 2012

Abstract: A power converter topology operates as a switching capacitor (capacitive voltage divider) converter during a first, preferably short portion of a switching cycle to provide excellent dynamic transient response, and as a pulse width modulated converter during a second portion of a switching cycle to provide flexibility of voltage regulation and generality of application. This topology can be made self-driven and is capable of zero voltage switching. Therefore, the power converter can be used as one of the plurality of branches of a multi-phase converter to enhance transient response. The respective branches can also be independently optimized for particular load levels and can be operated independently in a phase shedding manner to improve efficiency at low load. Further, the power converter or respective branches of a multi-phase power converter are compatible with non-linear control to further improve dynamic response.

VTIP 03-142

*Nanoscale Metal Paste for Interconnect and Method of Use*

Guo-Quan Lu, Guangyin Lei, Jesus N. Calata

[US PATENT: 8,257,795 \(for NBE\)](#)

Issue Date: September 4, 2012

Abstract: A paste including metal or metal alloy particles (which are preferably silver or silver alloy), a dispersant material, and a binder is used to form an electrical,

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mechanical or thermal interconnect between a device and a substrate. By using nanoscale particles (i.e., those which are less than 500 nm in size and most preferably less than 100 nm in size), the metal or metal alloy particles can be sintered at a low temperature to form a metal or metal alloy layer which is desired to allow good electrical, thermal and mechanical bonding, yet the metal or metal alloy layer can enable usage at a high temperature such as would be desired for SiC, GaN, or diamond (e.g., wide bandgap devices). Furthermore, significant application of pressure to form the densified layers is not required, as would be the case with micrometer sized particles. In addition, the binder can be varied so as to insulate the metal particles until a desired sintering temperature is reached; thereby permitting fast and complete sintering to be achieved.

### VTIP 09-028

#### *Electromagnetic Interference Noise Separator*

Shuo Wang, Fred C. Lee

[US PATENT: 8,125,291](#)

Issued: February 28, 2012

Abstract: Improved performance of a noise separator circuit capable of separating common mode (CM) and differential mode (DM) components of electromagnetic interference (EMI) noise are provided by arrangement of terminating impedances such that the circuit is fully symmetric with respect to a pair of input ports. The noise separator circuit is further improved by perfecting features for canceling effects of parasitic inductances and capacitances, parasitic capacitance and inductance between circuit connections such as printed circuit board traces, minimizing leakage inductance effects of pairs of coupled inductors and mutual inductance effects between pairs of coupled inductors, providing sufficient magnetizing inductance for low frequency response, and preventing saturation of inductors using switched attenuators, providing a plurality of ground planes, choices of terminating resistors and circuit layout

### VTIP 06-081

#### *Method and Apparatus for Three-Dimensional Integration of Embedded Power Module*

Michele H. Lim, Zhenxian Liang, J. Daan van Wyk

[US PATENT: 7,932,800](#)

Issued: April 26, 2011

Abstract: A modified planar Low Temperature Co-Fired Ceramic (LTCC) high conductance inductor, embedding a large cross section conductor, supports a stacked arrangement of heat spreader, inductor and active device layers. Interlayer electrical connections connect the layers. Optionally, a DC-DC converter includes the modified planar LTCC high conductance inductor, embedding a large cross section conductor,

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supporting a stacked arrangement of heat spreader, capacitor and active device layers, the active devices layer including the switching transistors. The active devices layer may include semiconductor dies embedded in a substrate.

### VTIP 07-078/07-079/07-080

#### *Quasi-Parallel Voltage Regulator*

Ming Xu, Julu Sun, Ya Liu, Fred C. Lee

[US PATENT: 7,872,886](#)

Issued: January 18, 2011

Abstract: Improved regulation and transient response are provided by a power supply architecture providing both unregulated and regulated voltage converters in parallel but deriving input power from separate power supplies connected in series wherein regulated and unregulated branches each provide a substantially fixed and constant proportion of the output current. The series connection of input power sources may provide a further feedback mechanism in addition to feedback for regulation which enhances overall performance. As a perfecting feature of the invention, inductor-less resonant converters which are switched in an interleaved fashion may be used in the unregulated branch while substantially cancelling the characteristic large output voltage ripple thereof.

### VTIP 05-063 (Divisional)

#### *Multiphase Voltage Regulator Having Coupled Inductors with Reduced Winding Resistance*

Yan Dong, Ming Xu, Fred C. Lee

[US PATENT: 7,821,375](#)

Issued: October 26, 2010

Abstract: A multiple phase buck converter or boost converter, or buck-boost converter has an inductor in each phase. The inductors are inversely coupled. In a first embodiment, the converter includes a toroidal magnetic core with inductors extending under and over opposite sides of the toroidal magnetic core. The coupled inductors are thereby inversely coupled and have a relatively low ohmic resistance. In a second embodiment, the converter comprises a ladder-shaped magnetic core (i.e. having parallel sides, and connecting rungs). In this case, the inductors extend under the sides, and over the rungs. Each inductor is disposed over a separate rung. The ladder-shaped magnetic core is preferably disposed flat on a circuit board. Inverse coupling and low ohmic resistance are also provided in the second embodiment having the ladder structure.

### VTIP 06-017

## CPES Patent Portfolio

### *Reducing Common Mode Noise of Power Factor Correction Converters Using General Balance Concept*

Shuo Wang, Fred C. Lee, Pengju Kong

[US PATENT: 7,804,281](#)

Issued: September 28, 2010

Abstract: Common mode (CM) noise is substantially canceled in a switching power supply circuit such as a boost converter by providing a split inductor and analyzing the switching power supply circuit as a bridge circuit formed of the switch, portions of the split inductor and parasitic capacitances of respective portions of the power supply circuit. The bridge can then be balanced by addition of capacitance in parallel with the parasitic capacitance of a respective portion of the power supply circuit or dividing the split inductor such that a ratio of inductances of respective portions of the split inductor approximates a ratio of parasitic capacitances of the respective power supply circuit portions which may be measured or otherwise empirically determined. CM noise reduction of up to 40 db can be achieved without symmetric circuit design, addition of circuit elements or complex filtering having added cost, space requirements and power losses. Further, such a reduction in common mode noise allows simple EMI filtering arrangements to be employed further reducing cost and space requirements for the power supply circuit.

### VTIP 06-038

#### *Coupled-Inductor Multi-Phase Buck Converters*

Ming Xu, Fred C. Lee, Yucheng Ying

[US PATENT: 7,791,321](#)

Issued: September 7, 2010

Abstract: In a multi-phase power converter, efficiency is increased and ripple reduced while maintaining transient response and dynamic performance improved by electrically coupling secondary windings of transformers or provided for inductors of respective phases such that current to a load is induced in each phase by current in another phase. Magnetic coupling can also be provided between phases using a multi-aperture core of a configuration which minimizes primary winding length and copper losses. Efficiency at light load is enhanced by controlling current in the series connection of secondary windings in either binary or analog fashion.

### VTIP 06-136

#### *Asymmetrical Interleaving Strategy for Multi-Channel Power Converters*

Chuanyun Wang, Ming Xu, Fred C. Lee

[US PATENT: 7,746,675](#)

Issued: June 29, 2010

## CPES Patent Portfolio

Abstract: In a power converter having  $m=$ two or more channels of power factor correction (PFC) circuits connected in parallel and an electromagnetic interference (EMI) filter connected in series therewith, phase shifts in switching between the respective PFC channels can allow increase of EMI filter corner frequency allowing reduction of size and cost of the EMI filter at some switching frequencies. Asymmetrical phase shifts (other than  $360^\circ/m$ ) such as  $360^\circ/2m$  and other phase shifts and variations in  $m$  allow increase of EMI filter corner frequency at switching frequencies where symmetrical,  $360^\circ/m$  phase shifts provide no benefit to EMI filter design by providing cancellation or partial cancellation of different harmonics of the switching noise; which cancellation may be arranged to be complementary to the EMI filter function at more than one peak of the noise spectrum. (Such asymmetrical phase shifts do not significantly increase ripple and consequent switching noise). Alteration of  $m$  and corresponding alteration of phase shift may be performed adaptively for purposes of improving efficiency at light loads and the like.

### VTIP 06-062

#### *Non-Isolated Bus Converters with Voltage Divider Topology*

Ming Xu, Julu Sun, Fred C. Lee

[US PATENT: 7,746,041](#)

Issued: June 29, 2010

Abstract: A voltage converter having four switches Q1, Q2, Q3, Q4, connected in series and operated in pairs in a complementary fashion. An input voltage is provided across the four switches. A middle capacitor is connected in parallel with two middle switches, Q2, Q3. Voltage output is provided across switches Q3 and Q4 (i.e. at a midpoint of the four switches). Series-connected output capacitors can be connected in parallel with the set of four switches. The middle capacitor alone or in combination with parallel connected capacitors, when connected to the input voltage or output terminals functions as a capacitive voltage divider for voltage conversion and/or regulation with extremely high efficiency and which can provide either step-down or step-up function. Also, an output inductor can be provided as a perfecting feature to further increase efficiency. Alternatively, two of the four switches can be replaced with rectifying diodes. Alternatively, the voltage converter has two or more sets of four switches connected in parallel. The two sets can be connected by resistor-capacitor ladder, or an inductor-capacitor ladder for charge/voltage sharing to reduce voltage ripple.

### VTIP 07-113

#### *Multi-Element Resonant Converters*

Dianbo Fu, Fred C. Lee, Ya Liu, Ming Xu

[US PATENT: 7,742,318](#)

## CPES Patent Portfolio

Issued: June 22, 2010

Abstract: A resonant switched power converter having switching frequency controlled in response to an output voltage thereof achieves over-current protection such as at start-up or under short circuit conditions using a resonant tank circuit which provides a notch filter in addition to a band pass filter. An additional band pass filter provided in the resonant tank circuit achieves increased power transfer to a load and reduced circulating resonant currents and conduction losses. The inductances of the preferred LCLCL tank circuit or other tank circuit with two pass band filters and a notch filter may be integrated into a single electrical component.

VTIP 06-128

### *Digital Power Supply Control*

Jian Li, Yang Qiu, Ming Xu, Fred C. Lee

[US PATENT: 7,705,577](#)

Issued: April 27, 2010

Abstract: A switched voltage regulator provides improved regulation at a lower clock rate/sampling frequency (e.g. several orders of magnitude lower than would be required for comparable regulation) while using a low resolution digital pulse width modulator such that limit cycle oscillations occur (and thus of low cost and complexity and small size) by limiting the amplitude of limit cycle oscillations which therefore need not be avoided by more complex arrangements which are not commercially feasible. Limiting of amplitude of limit cycle oscillations is achieved by adding essentially a digitized ripple voltage signal corresponding to the difference between the output of the voltage regulator and an average output of the voltage regulator as an input to the digital pulse width modulator. Performance of this arrangement may be enhanced by adding a ramp signal to the digitized ripple voltage signal and even further enhanced by limiting the ramp signal to a range which corresponds to steady state operation but not transients.

VTIP 05-063

### *Multiphase Voltage Regulator Having Coupled Inductors with Reduced Winding Resistance*

Ming Xu, Yan Dong, Fred C. Lee

[US PATENT: 7,649,434](#)

Issued: January 19, 2010

Abstract: A multiple phase buck converter or boost converter, or buck-boost converter has an inductor in each phase. The inductors are inversely coupled. In a first embodiment, the converter includes a toroidal magnetic core with inductors extending under and over opposite sides of the toroidal magnetic core. The coupled inductors are thereby inversely coupled and have a relatively low ohmic resistance. In



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a second embodiment, the converter comprises a ladder-shaped magnetic core (i.e. having parallel sides, and connecting rungs). In this case, the inductors extend under the sides, and over the rungs. Each inductor is disposed over a separate rung. The ladder-shaped magnetic core is preferably disposed flat on a circuit board. Inverse coupling and low ohmic resistance are also provided in the second embodiment having the ladder structure.

### VTIP 05-052

#### *Co-Fired Ceramic Inductor with Variable Inductance, and Voltage Regulator Having Same*

Michele Lim, J. Daan Van Wyk

[US PATENT: 7,638,988](#)

Issued: December 29, 2009

Abstract: Ceramic inductors are made from stacked sheets of co-fired ceramic. At least one of the ceramic sheets has a slot with a conductor disposed in the slot. The conductor has a thickness equal to a thickness of the ceramic sheet containing the slot. The conductor has a large thickness (compared to prior art co-fired ceramic inductors) and therefore can carry large currents. The present ceramic inductor can be used in power electronics applications due to the ability to carry large currents. The present ceramic inductor preferably has an inductance that decreases with increasing current. A decreasing inductance characteristic tends to increase energy efficiency in a voltage regulator when the inductor is used as an output inductor. Specifically, the variable inductance tends to substantially increase energy efficiency at low current loads without adversely affecting efficiency at high loads.

### VTIP 03-117

#### *Input Current Sensing AVP Method for Future VRM*

Ming Xu, Fred C. Lee, Jinghai Zhou

[US PATENT: 7,605,572](#)

Issued: October 20, 2009

Abstract: A voltage converter provides a desired voltage droop with load while avoiding output current sensing and active control/feedback circuits and avoiding excessive power dissipation from passive components by placing a sensing resistor in the low current, switched input circuit of the voltage converters. Therefore, the resistor conducts only when a switch controlling voltage conversion is conductive, generally at very low duty cycle and low current.

### VTIP 06-130

*Common Mode Noise Reduction using Parasitic Capacitance Cancellation*

Shuo Wang, Fred C. Lee

[US PATENT: 7,602,159](#)

Issued: October 13, 2009

Abstract: A negative capacitance is developed by configuring an inductor as two inversely or opposingly coupled windings having different numbers of turns and connecting a capacitance to a center tap between the two windings. The negative capacitance is developed on the side of the inductor having the winding with the greater number of turns. The negative capacitance so developed may be advantageously be used to cancel any capacitance or parasitic capacitance desired for reducing power loss, increasing switching speed or reducing or eliminating common mode noise in a switched circuit such as a switched power converter.

VTIP 07-025

*Phase Compensation Driving Scheme for Synchronous Rectifiers*

Dianbo Fu, Fred C. Lee

[US PATENT: 7,602,154](#)

Issued: October 13, 2009

Abstract: Phase compensation of a voltage appearing on physical terminals of a synchronous rectifier switching element such as a MOSFET is used to substantially eliminate effects of package inductance of the synchronous rectifier and thus approximate the actual voltage across the circuit element providing synchronous rectification in, for example, a switching power converter. By doing so and using the phase compensated signal to control the synchronous rectifier, switching time may be more suitably controlled to improve efficiency of the synchronous rectifier by substantially eliminating body diode conduction and body diode reverse recovery effects.

VTIP 04-085 (Divisional)

*Hybrid Filter For High Slew Rate Output Current Application*

Ming Xu, Yuancheng Ren, Fred C. Lee, Andrew P. Schmit

[US PATENT: 7,583,065](#)

Issued: September 1, 2009

Abstract: An active linear regulator circuit in parallel with a filter capacitor of a switching voltage regulator injects current to a load only when the switching regulator and capacitor cannot supply adequate current to follow high frequency load transients in a manner which is compatible with adaptive voltage positioning (AVP) requirements. Control of current injection and determination of the insufficiency of current from the switching regulator and capacitors is achieved by impedance matching of the linear regulator to the switching regulator. The linear regulator thus

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operates at relatively low current and duty cycle to limit power dissipation therein. By matching impedances and increasing the bandwidth of the switching regulator, filter capacitor requirements can be reduced to the point of being met entirely by packaging and/or on-die capacitors which may be placed close to or at the point of load to reduce parasitic inductance, as can the linear regulator.

### VTIP 06-012

#### *Hybrid Control Methods for Digital Pulse Width Modulator (DPWM)*

Jian Li, Dong Sam Ha, Yang Qiu, Ming Xu, Fred C. Lee

[US PATENT: 7,570,037](#)

Issued: August 4, 2009

Abstract: A digital pulse width modulator leverages clock frequency to achieve very fine duty cycle resolution by using a constant number of time slots for each state of a pulse signal and varying the number of time slots in a switching cycle within acceptable limits for variation of the switching cycle frequency or by using two relatively low frequency clocks of slightly differing frequency and selecting pulse leading and trailing edges in accordance with pulses output there from. A fine resolution of duty cycle adjustment can thus be provided corresponding to a much higher effective clock frequency than is actually used; allowing improvement of efficiency of clock and switching circuits, particularly in switching voltage regulator applications.

### VTIP 04-085

#### *Hybrid Filter for High Slew Rate Output Current Application*

Ming Xu, Yuancheng Ren, Fred C. Lee, Andrew P. Schmit

[US PATENT: 7,560,912](#)

Issued: July 14, 2009

Abstract: An active linear regulator circuit in parallel with a filter capacitor of a switching voltage regulator injects current to a load only when the switching regulator and capacitor cannot supply adequate current to follow high frequency load transients in a manner which is compatible with adaptive voltage positioning (AVP) requirements, control of current injection and determination of the insufficiency of current from the switching regulator and capacitors is achieved by impedance matching of the linear regulator to the switching regulator. The linear regulator thus operates at relatively low current and duty cycle to limit power dissipation therein. By matching impedances and increasing the bandwidth of the switching regulator, filter capacitor requirements can be reduced to the point of being met entirely by packaging and/or on-die capacitors which may be placed close to or at the point of load to reduce parasitic inductance, as can the linear regulator.

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VTIP 06-019

### *Cancellation of Inductor Winding Capacitance*

Shuo Wang and Fred C. Lee

[US PATENT: 7,554,423](#)

Issued: June 30, 2009

Abstract: An inductor device or filter such as an electromagnetic interference (EMI) filter which includes an inductor provides cancellation of parasitic capacitance of the inductor and extends high frequency performance of the inductor or filter by providing the inductor using split windings and including capacitors to couple signals corresponding to those which are passed by the equivalent parallel capacitance of the inductor to another split winding or an inductor in the ground return path. Cancellation of parasitic capacitance is provided for differential mode and common mode split windings where the split windings may be either inductively coupled or not. Forming the split windings as a bifilar winding to increase coupling coefficient further improves performance and allows cancellation (as distinct from parasitic capacitance reduction) and avoidance of resonance in circuits in which an inductor is not permitted in the ground return path.

VTIP 06-019 (Continuation-in-part)

### *Generalized Cancellation of Inductor Winding Capacitance*

Shuo Wang and Fred C. Lee

[US PATENT: 7,548,137](#)

Issued: June 16, 2009

Abstract: An inductor device or filter such as an electromagnetic interference (EMI) filter which includes an inductor provides cancellation of parasitic capacitance of the inductor and extends high frequency performance of the inductor or filter by using an inductor network (a special case being split windings) and including capacitors to couple signals corresponding to those which are passed by the equivalent parallel capacitance of an inductor of a network of inductors such as in a multi-phase power supply of voltage converter to another inductor terminal, ground or an inductor in the ground return path. Cancellation of parasitic capacitance is provided for differential mode and common mode windings where the windings may be either inductively coupled or not. Forming the windings as a bifilar winding to increase coupling coefficient further improves performance and allows cancellation (as distinct from parasitic capacitance reduction) and avoidance of resonance in circuits in which an inductor is not permitted in the ground return path. Different inductance values and turns ratios of any or all inductors of the network, including multi-phase networks, may be accommodated.

VTIP 02-118

*Discharge Lamp Lighting Control Device*

Fred C. Lee, Jinghai Zhou, Yan Jiang, Masanao Okawa, Dung A. Tran, Hiroyasu Eriguchi

[US PATENT: 7,391,165 \(Sponsored by MEW, NOT IP SHARING\)](#)

Issue Date: June 24, 2008

Abstract: A discharge lamp lighting control device (100) having a DC power converter, a power factor improving power converter (1), a polarity reversing circuit (2), a starter circuit (3), and a controller (4). The power factor improving power converter 1 includes a switching device S, a power factor improver, and a power converter. The power factor improver operates to smooth a rectified voltage by storing energy in a first inductive device L1 and by discharging energy from a second inductive device L2, in which the first and second inductive devices are magnetically coupled together. The storing and discharging is performed by turning ON and OFF the switching device S. A predetermined DC voltage is converted by energy stored and discharged by a third inductive device L3 in response to the turning ON and OFF of the switching device S.

VTIP 04-092

*Self-Driven Scheme for Synchronous Rectifier Having No Body Diode*

Ming Xu, Julu Sun, Jinghai Zhou, Fred C. Lee

[US PATENT: 7,265,525](#)

Issue Date: September 4, 2007

Abstract: A voltage converter uses a component such as a JFET or four-terminal power MOSFET having no body diode and exhibiting no body diode conduction characteristic as a synchronous rectifier to reduce switching losses and body diode conduction losses and to support high frequency switching so that use of smaller components and higher current densities can be achieved. These effects are enhanced by a self-driven circuit utilizing positive feedback to enhance switching speed and reduce switching losses which increase with switching frequency.

VTIP 04-090

*Power Converters Having Output Capacitor Resonant with Autotransformer Leakage Inductance*

Yuancheng Ren, Julu Sun, Ming Xu, Fred C. Lee

[US PATENT: 7,254,047](#)

Issue Date: August 7, 2007

Abstract: Power converters having reduced body diode conduction loss, reduced reverse recovery loss and lower switching noise, among other benefits, have a resonant capacitor Cr connected across an unfiltered output. The resonant capacitor Cr resonates with the leakage inductance Lk of the transformer. The resonant

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capacitor and leakage inductance are selected such that  $\frac{1}{2}$  a LC resonance period is equal to an ON time of each secondary switch S1 S2. The resonance provides zero current switching for secondary switches S1 S2, eliminates zero body diode conduction during dead times, and eliminates reverse recovery losses in the secondary switches. The present invention is applicable to many different circuit topologies such as full bridge, active clamp forward, push-pull forward, and center-tap secondary. The present converters provide high energy conversion efficiency and high frequency operation.

### VTIP 05-064

#### *Current Sensing in Multiple Coupled Inductors by Time Constant Matching to Leakage Inductance*

Yan Dong, Ming Xu, Fred C. Lee

[US PATENT: 7,233,132](#)

Issue Date: June 19, 2007

Abstract: Voltage regulators often have coupled output inductors because coupled output inductors provide improvements in cost and efficiency. Coupled inductors are often used in multi-phase voltage regulators. Feedback control of voltage regulators often requires accurate and responsive sensing of output current. Provided is a technique for accurately sensing the magnitude of output current in coupled inductors. An RC circuit (comprising a resistor and capacitor in series) is connected in parallel with the coupled inductor. The inductor has a leakage inductance  $L_k$  and a DC (ohmic) resistance of DCR. The resistor and capacitor are selected such that an RC time constant is equal to an  $L/R$  time constant of  $L_k/DCR$ . With the matching time constants, a sum of voltage on the capacitors is accurately proportional to a sum of currents flowing in the output inductors. Also provided is a technique for sensing current when an uncoupled center tap inductor is present.

### VTIP 05-040

#### *Multiphase Voltage Regulator Having Coupled Inductors with Reduced Winding Resistance*

Jinghai Zhou, Fred C. Lee, Ming Xu, Yan Dong

[US PATENT: 7,199,695](#)

Issue Date: April 3, 2007

Abstract: A multiple phase buck converter or boost converter, or buck-boost converter has an inductor in each phase. A magnetic core with a unique woven topology provides inverse coupling between the inductors. The inductors can comprise straight conductors since the magnetic core has the woven topology wrapped around each inductor. The inductors have a reduced electrical resistance since they are straight and do not loop around the magnetic core. The reduced

## CPES Patent Portfolio

electrical resistance increases energy efficiency and improves transient response of the circuit. The magnetic core can comprise top and bottom portions that are magnetically connected. The inductors can comprise straight circuit board traces and the circuit board can have holes to accommodate the magnetic core.

### VTIP 03-115

#### *Power Converters having Capacitor Resonant with Transformer Leakage Inductance*

Yuancheng Ren, Fred C. Lee, Ming Xu

[US PATENT: 7,196,914](#)

Issue Date: March 27, 2007

Abstract: Power converters having reduced body diode conduction loss, reduced reverse recovery loss and lower switching noise, among other benefits, have a resonant capacitor  $C_r$  connected across an unfiltered output. The resonant capacitor  $C_r$  resonates with the leakage inductance  $L_k$  of the transformer. The resonant capacitor and leakage inductance are selected such that  $1/2$  a LC resonance period is equal to an ON time of each secondary switch  $S_1$   $S_2$ . The resonance provides zero current switching for secondary switches  $S_1$   $S_2$ , eliminates zero body diode conduction during dead times, and eliminates reverse recovery losses in the secondary switches. The present invention is applicable to many different circuit topologies such as full bridge, active clamp forward, push-pull forward, and center-tap secondary. The present converters provide high energy conversion efficiency and high frequency operation.

### VTIP 04-004

#### *Buck Converter with High Efficiency Gate Driver Providing Extremely Short Dead Time*

Yuancheng Ren, Fred C. Lee

[US PATENT: 7,184,281](#)

Issue Date: February 27, 2007

Abstract: A buck converter has a driver circuit with a drive transformer that provides complementary voltages to the buck converter switches. The drive transformer may have two secondary windings, with one winding for each converter switch. As one converter switch experiences a rising gate voltage, the other converter switch experiences a falling gate voltage. Since both converter switches are controlled by the same driver switches, the converter switch dead time is very small. Preferably, at least one converter switch has a voltage shift circuit connected to the gate electrode. Adjustment of the voltage shift magnitude will advance or delay the turn on and turn off times of the switch. Hence, the converter switch dead time can be precisely adjusted by varying the voltage shift magnitude. Preferably, the converter switch dead time is less than 1 or 2 nanoseconds.

## CPES Patent Portfolio

### VTIP 04-031

#### *EMI Filter and Frequency Filters Having Capacitor with Inductance Cancellation Loop*

Shuo Wang, Fred C. Lee, Williem Gerhardus Odendaal

[US PATENT: 7,180,389](#)

Issue Date: February 20, 2007

Abstract: An electromagnetic interference (EMI) filter or frequency filters (e.g. bandpass or band reject filters) in which a capacitor has an inductance cancellation loop. Inductive coupling between capacitors can allow undesired high frequencies to propagate across a filter. This is particularly a concern when the capacitors are oriented in parallel. In the present invention, the inductance cancellation loop is disposed adjacent to one capacitor so that mutual inductance between the capacitors is reduced. The attenuation of the filter at high frequencies is thereby increased. The loop can increase voltage attenuation of an EMI filter by about 20 dB. In another aspect, inductors in the filter are oriented horizontally relative to a circuit board. Horizontal orientation reduces leakage inductance coupling between the inductors and circuit board traces, and between the inductor and capacitors, thereby preventing unwanted propagation of high frequencies. Both measures in combination can provide a voltage attenuation increase of 30 dB.

### VTIP 03-110

#### *Adaptive Bus Voltage Positioning for Two-Stage Voltage Regulators*

Ming Xu, Jinghai Zhou, Yuancheng Ren, Fred Lee, Jia Wei

[US PATENT: 7,161,335](#)

Issue Date: January 9, 2007

Abstract: Alteration of voltage input to a voltage regulator output stage from a V.sub.bus regulator stage in a two-stage voltage regulator provides optimal V.sub.bus voltage placement for a wide range of current loads to increase voltage regulator efficiency and is particularly suited to CPUs having power-saving sleep modes of operation. An optimal voltage is selected or developed in response to information concerning operational mode or current consumption of the powered device. As a perfecting feature of one embodiment of the invention in which a discrete V.sub.bus voltage is selected based on operational mode, the selected voltage is adjusted to further optimize the matching of the V.sub.bus voltage placement to the load and provides a continuous range of voltages. In a second embodiment the entire V.sub.bus positioning function is performed in response to current load information. A feed-forward arrangement is provided to avoid transient spikes as the V.sub.bus voltage placement is altered.

### VTIP 04-091/04-042 (CIP of 03-110)



*Two-Stage Voltage Regulators with Adjustable Intermediate Bus Voltage, Adjustable Switching Frequency, and Adjustable Number of Active Phases*

Yuancheng Ren, Fred C. Lee, Ming Xu

[US PATENT: 7,071,660](#)

Issue Date: July 4, 2006

Abstract: A two-stage power converter that dynamically adjusts to output current requirements includes a first stage regulator that provides power to a second stage regulator. The first stage can be a buck converter, and the second stage can be a multiple-phase buck converter. The output voltage of the first stage (intermediate bus voltage  $V_{bus}$ ) is varied according to the load current to optimize conversion efficiency. To provide maximum efficiency, the  $V_{bus}$  voltage is increased as load current increases. The  $V_{bus}$  voltage provided by the first stage can be varied by duty cycle or operating frequency control. In another embodiment, the switching frequency of the second stage is varied as output current changes so that output current ripple is held constant. In an embodiment employing a multiple-phase buck converter in the second stage, the number of operating phases is varied as output current changes.

VTIP 03-116/02-097

*Self-Driven Circuit for Synchronous Rectifier DC/DC Converter*

Yuancheng Ren, Fred C. Lee, Ming Xu, Douglas Sterk

[US PATENT: 7,016,203](#)

Issue Date: March 21, 2006

Abstract: A power converter having a primary circuit (e.g. full bridge) and a secondary circuit (e.g. current doubler) has switches in the secondary circuit that are controlled by a drive circuit. The drive circuit is connected to a swing node in the primary circuit, and is powered by the primary circuit. The drive circuit has an isolation device such as a transformer to provide electrical isolation between the primary circuit and secondary circuit. The drive circuit provides a current source for driving the secondary switch gates, thereby reducing power consumption. The present drive circuit provides clean gate drive signals without noise and oscillations. The drive circuits of the invention are simple, and require only a few components.

VTIP 03-111/03-014/02-060

*Quasi-Resonant DC-DC Converters with Reduced Body Diode Loss*

Ming Xu, Fred C. Lee, Jinghai Zhou, Yang Qiu

[US PATENT: 6,989,997](#)

Issue Date: January 24, 2006

Abstract: Buck converters having a resonant inductor  $L_r$ , resonant capacitor  $C_r$ , and synchronous switch  $Q_3$  that together provide reduced switching loss and soft switching. In operation, the resonant inductor  $L_r$  is charged during a time period  $A$ .

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Then,  $L_r$  is freewheeling and provides current to an output inductor  $L_o$ . Then,  $Q_3$  is turned OFF, and energy from the resonant inductor  $L_r$  charges the resonant capacitor  $C_r$ . Finally, energy from the resonant capacitor  $C_r$  is provided to the output inductor and load. The output power can be adjusted by phase control of the operation of switch  $Q_3$ . In alternative embodiments, the circuit has a pair of coupled inductors  $L_1$   $L_2$  or an isolation transformer 40. The coupled inductors have a polarity selected so that the output voltage is reduced, thereby allowing top switch  $Q_1$  to have a greater duty cycle. These circuits feature no body diode loss in the switch  $Q_3$ .

### VTIP 01-097

#### *Solid-State DC Circuit Breaker*

Qin Huang, Xigen Zhou, Zhenxue Xu

[US PATENT: 6,952,335](#)

Issue Date: October 4, 2005

Abstract: A high-speed, solid-state circuit breaker is capable of interrupting high DC currents without generating an arc, and it is maintenance-free. Both the switch and the tripping unit are solid-state, which meet precise protection requirements. The high-speed, solid-state DC circuit breaker uses an emitter turn-off (ETO) thyristor as the switch. The ETO thyristor has an anode, a cathode and first, second and third gate electrodes. The anode is connectable to a source of DC current, and the cathode is connectable to a load. A solid-state trip circuit is connected to the first, second and third gate electrodes for controlling interruption of DC current to the load by turning off said ETO thyristor.

### VTIP 02-096

#### *Multi-Phase Interleaving Isolated DC/DC Converter*

Ming Xu, Fred C. Lee, Jinghai Zhou

[US PATENT: 6,944,033](#)

Issue Date: September 13, 2005

Abstract: A converter has a transformer with primary and secondary windings each having  $n$  coils in a series-series arrangement connected to primary and secondary sides. The primary side has  $n$  primary legs each having a top switch and a bottom switch and connected to the primary winding therebetween. The secondary side has  $n$  secondary legs, each secondary leg has a synchronous rectifier switch and an output filter inductor connected to the secondary winding therebetween. A complimentary control for the primary side comprising a gate driver transformer with primary winding in series with a DC blocking capacitor connected to a drain and a source of the top switch of each primary leg, and a gate drive transformer, for each primary leg, with secondary winding containing a leakage inductor and in series with a DC blocking

## CPES Patent Portfolio

capacitor and a damping resistor connected to gate and source of the secondary side synchronous rectifier.

### VTIP 96-037

#### *Emitter Turn-Off Thyristors (ETO)*

Alex Qin Huang

[US PATENT: 6,933,541](#)

Issue Date: August 23, 2005

Abstract: A family of emitter controlled thyristors employs plurality of control schemes for turning the thyristor on and off. In a first embodiment of the present invention, a family of thyristors are disclosed, all of which comprise a pair of MOS transistors, the first of which is connected in series with the thyristor and a second one provides a negative feedback to the thyristor gate. A negative voltage applied to the gate of the first MOS transistor causes the thyristor to turn on to conduct high currents. A zero to positive voltage applied to the first MOS gate causes the thyristor to turn off. The negative feedback insures that the thyristor only operates at its breakover boundaries of the latching condition with the NPN transistor portion of the thyristor operating in the active region. Under this condition, the anode voltage  $V_A$  continues to increase without significant anode current increase. Emitter turn-off (ETO) thyristor fabrication packages are also disclosed having packaged semiconductor devices controlling the thyristor.

### VTIP 99-019 ( Continuation)

#### *Accelerated Commutation for Passive Clamp Isolated Boost Converters*

Lizhi Zhu, Jih-Sheng Lai, Fred C. Lee

[US PATENT: 6,876,556](#)

Issue Date: April 5, 2005

Abstract: An efficient and cost effective bidirectional DC/DC converter reduces switch voltage stress via accelerated commutation allowing use of a low-cost passive clamp circuit in boost mode. The converter includes a primary circuit, transformer and secondary circuit. The primary circuit takes the form of a "full bridge converter," a "push-pull converter," or an "L-type converter". The primary circuit may include a dissipator such as a snubber circuit or small buck converter. A secondary side of the transformer is momentarily shorted by the secondary circuit by, for example, turning on at least two switches in the secondary circuit simultaneously for a minimal calibratable period when a pair of primary circuit controllers turn off to protect the primary circuit switches from voltage spikes during switching conditions.

### VTIP 99-019

#### *Accelerated Commutation for Passive Clamp Isolated Boost Converters*

## CPES Patent Portfolio

Lizhi Zhu, Jih-Sheng Lai, Fred C. Lee

[US PATENT: 6,452,815](#)

Issue Date: September 17, 2002

Abstract: This invention is an efficient and cost-effective bi-directional DC/DC converter that can effectively reduce the switch voltage stress (such as a semiconductor) with an accelerated commutation circuit, and thus allowing a low-cost passive clamp circuit to be used. Specifically, the invention is a method and system to accelerate commutation for passive-clamped isolated boost converters, which can also be a boost mode in a bi-directional DC/DC converter. A primary circuit has a snubber comprising a diode, a capacitor and an energy dissipater (such as a resistor or small buck converter). The primary circuit can be a "full bridge converter" or a "push-pull converter" or an "L-type converter" configuration. The commutation of the present invention protects the primary circuit switches from voltage spikes during switching conditions. The present invention can shorten a secondary circuit by turning on at least two switches on the secondary circuit simultaneously for a minimal calibratable period while primary circuit diagonal switches turn off. The present invention also has a means to allow a smooth transition between a choke current and a primary current. Primary current increases linearly through the snubber circuit during circuit startup, thus protecting the primary circuit controllers.

VTIP 03-015

*Bridge-Buck Converter with Self-Driven Synchronous Rectifiers*

Ming Xu, Fred C. Lee, Jinghai Zhou

[US PATENT: 6,859,372](#)

Issue Date: February 22, 2005

Abstract: A non-isolated bridge-buck DC--DC converter has self-driven synchronous rectifiers Q5 Q6 in the buck circuits 28 30. Gate electrodes of the synchronous rectifiers Q5 Q6 are connected to midpoints 24A 24B of the bridge circuit. The voltage at the midpoints provides the necessary voltage waveform for switching the synchronous rectifiers Q5 Q6. In another aspect of the invention, voltage shift circuits 34 are provided between the midpoints and the gates of the synchronous rectifiers. The voltage shift circuits are necessary in some embodiments to make sure that the synchronous rectifiers are turned completely OFF when necessary. The present invention provides a more power efficient and less expensive technique for controlling the synchronous rectifiers compared to conventional external driver circuitry.

VTIP 02-097

*Self-Driven Circuit for Synchronous Rectifier DC/DC Converter*

Ming Xu, Fred C. Lee, Yuancheng Ren

[US PATENT: 6,819,574](#)

## CPES Patent Portfolio

Issue Date: November 16, 2004

Abstract: A power converter having a primary circuit (e.g. full bridge) and a secondary circuit (e.g. current doubler) has switches in the secondary circuit that are controlled by a drive circuit. The drive circuit is connected to a swing node in the primary circuit, and is powered by the swing node. The drive circuit has an isolation device such as a transformer to provide electrical isolation between the primary circuit and secondary circuit. The drive circuit provides a current source for driving the secondary switch gates, thereby reducing power consumption. The present drive circuit provides clean gate drive signals without noise and oscillations. The drive circuits of the invention are simple, and require only a few components.

VTIP 01-040

### *Mounting and Heatsink Method For Piezoelectric Transformer*

Eric Baker, Weixing Huang, Dan Chen, Fred Lee

[US PATENT: 6,800,985](#)

Issue Date: October 5, 2004

Abstract: The present invention relates to a process for mounting and heatsinking a piezoelectric transformer (PT). The method provides a method to mount a PT, while allowing heat generated in the device to be conducted away to the mounting surface. The method can be used in piezoelectric transformer based ballasts and power supplies such that high power levels may be achieved due to minimizing thermal constraints on the devices.

VTIP 01-100/01-003/01-002/01-001/00-128

### *Multiphase Clamp Coupled-Buck Converter and Magnetic Integration*

Peng Xu, Kaiwei Yao, Fred C. Lee, Mao Ye, Jia Wei

[US PATENT: 6,784,644](#)

Issue Date: August 31, 2004

Abstract: Voltage regulation, transient response and efficiency of a voltage regulator module (VRM) is improved where short duty cycles are necessitated by large differentials of input and output voltage by including at least one clamping of a tap of an inductance in series with an output of each of a plurality of parallel branches or phases which are switched in a complementary fashion or providing coupling between inductors of respective phases. Such coupling between inductors is achieved in a small module with an integrated magnetic structure. Reduced component counts are achieved while deriving built-in input and output filters. Principals of the invention can be extended to isolation applications and push-pull forward converts, in particular. A lossless clamping circuit is also provided allowing spike currents to be suppressed while returning power to the output of the VRM.

## CPES Patent Portfolio

VTIP 01-120

### *Method and Apparatus for Reduction Of Energy Loss Due to Body Diode Conduction in Synchronous Rectifiers*

Ming Xu, Fred C. Lee

[US PATENT: 6,781,853](#)

Issue Date: August 24, 2004

Abstract: A method and apparatus for preventing current flow through the integral body diode of an electronic switch (e.g. MOSFET) in the secondary circuit of a synchronous rectifier. In a conventional synchronous rectifier, body diode current 31a 31b occurs during dead times 32a 32b. In the present invention, current steering pulses 40 are applied to the secondary circuit to oppose freewheeling current flow through the integral body diode. The current steering pulses produce a current that maintains the body diode in a reverse-biased state. Also, body diode current 31a 31b is prevented in the invention by short-circuiting a primary winding 19 of a transformer. The present invention prevents body diode conduction energy losses, as well as reverse recovery losses. The present invention is applicable to many different kinds of synchronous rectifiers such as current doubling rectifiers, center-tapped rectifiers, full bridge rectifiers.

VTIP 02-122

### *Step-Down Buck Converter with Full Bridge Circuit*

Jia Wei, Fred C. Lee

[US PATENT: 6,757,184](#)

Issue Date: June 29, 2004

Abstract: A power converter with high efficiency, low component count, and high step down conversion capability. The converter has a full bridge circuit connected to a pair of buck output circuits. The full bridge circuit and buck circuits are not isolated. In one embodiment, a transformer is connected between the full bridge and buck circuits without providing isolation. In operation, the transformer is operated as an autotransformer, which results in reduced voltages and currents applied to the switches. As a result, the present invention is capable of reduced switching losses, lower output voltage and other benefits. The present invention also includes an embodiment having coupled inductors instead of a transformer. Also, the present invention includes embodiments having additional parallel buck output circuits for higher power and higher current capability.

VTIP 01-058

### *Method and Circuits for Reducing Dead Time and Reverse Recovery Loss in Buck Regulators*

Yuming Bai, Nick Sun, Alex Q. Huang

## CPES Patent Portfolio

### [US PATENT: 6,737,842](#)

Issue Date: May 18, 2004

Abstract: A buck regulator having a voltage sensor for sending a voltage reversal caused by freewheeling current from an output inductor in the regulator. Upon sensing a reversed voltage, the voltage sensor triggers a gate controller to turn on a switch in the regulator, and thereby terminate a dead time. The voltage sensor and gate controller are high speed circuits, and therefore can reduce the duration of the dead time. Reducing the dead time duration improves efficiency by reducing the duration of body diode conduction. The dead time can be reduced to less than a turn-on time of the body diode, thereby preventing charge buildup in the body diode, and, consequently, preventing reverse recovery loss in the body diode. The present invention improves electrical conversion efficiency, and allows for increased operating frequency in buck regulators.

### VTIP 01-113

#### *Emitter Turn-Off Thyristors and Their Drive Circuits*

Alex Q. Huang, Bin Zhang

### [US PATENT: 6,710,639](#)

Issue Date: March 23, 2004

Abstract: A family of emitter turn-off thyristors and their drive circuit comprise a gate turn-on (GTO) thyristor, a first switch, the drain of the first switch being connected to the cathode of the GTO thyristors, and a second switch connected between the gate of the GTO thyristor and the source of the first switch. The first switch consists of many paralleled metal oxide semiconductor field effect transistors (MOSFETs). The anode of the GTO thyristor and the source of the first switch serve as the anode and cathode, respectively, of the emitter turn-off thyristor. The emitter turn-off thyristor has four control electrodes: the gate of the GTO thyristor, the control electrode of the second switch, the gate of the first switch, and the cathode of the GTO thyristor. The drive circuit comprises a current sources circuit, a voltage clamp circuit, a current direction detector, and a control circuit. The ETO thyristor further comprises a current sensing and over-current detector circuit. The first switch is packaged in a printed circuit board.

### VTIP 00-135

#### *Self-Oscillating Electronic Discharge Lamp Ballast with Dimming Control*

Fengfeng Tao, Fred C. Lee

### [US PATENT: 6,696,803](#)

Issue Date: February 24, 2004

Abstract: A simplified electronic ballast for a discharge lamp which provides dimming by control of inverter frequency through modulation of magnetizing current in a

## CPES Patent Portfolio

transformer such that the switching frequency is made substantially independent of the load presented. The principle of frequency control in a manner independent of the load is extendable to other types of loads and power supplies and converters to regulate power coupled to the load. Clamping capacitors are used to replace other clamping circuits in order to allow current injection to be controlled by a simple variable voltage while frequency control by current injection provides enhanced circuit performance.

### VTIP 96-081

#### *Low Profile Magnetic Component with Planar Winding Structure Having Reduced Conductor Loss*

Ronald M. Wolf (Philips Research), Glenn Skutt, Liming Ye

[US PATENT: 6,650,217](#)

Issue Date: November 18, 2003

Abstract: A planar magnetic winding structure such as a transformer or inductor having an air gap in the core has a "keep away" region of 2 to 3 times the gap height in which there are no windings, reducing high frequency winding losses by 35 percent or more, without appreciable increases in low frequency winding losses. Such structures are useful, for example, in electronic ballasts for the lighting industry.

### VTIP 98-040

#### *High Input Voltage, High Efficiency, Fast Transient Voltage Regulator Module (VRM)*

Xunwei Zhou, Fred C. Lee

[US PATENT: 6,590,791](#)

Issue Date: July 8, 2003

Abstract: A high input-voltage push-pull forward voltage regulator module (VRM) has high efficiency and fast transient response. The VRM has a primary side wherein two switches and two primary transformer windings are alternately connected in a loop. A capacitor is connected between any of two interleaved terminations. The remaining two terminations are connected to input and ground respectively. The two primary transformer windings have the same number of turns. A number of secondary sides may be used such as, for example, a half wave rectifier or a center tapped secondary. The high input-voltage push-pull forward VRM has high efficiency and fast transient-response with reduced filter capacitance and inductance. Its magnetic components can be easily integrated. As a result, very high power density can be achieved. The device die size needed to achieve the required efficiency is reduced. And control is simple. Therefore, this topology is very cost effective.

### VTIP 99-020

#### *Start-Up Circuit and Control for High Power Isolated Boost DC/DC Converters*



## CPES Patent Portfolio

Lizhi Zhu, Jih-Sheng Lai, Fred C. Lee

[US PATENT: 6,587,356](#)

Issue Date: July 1, 2003

Abstract: The invention is a scheme for high power isolated full-bridge boost DC/DC converters to minimize the effect of in-rush current during start-up. A single pulse width modulation controller (PWM) is possible for the present invention for not only start-up but also normal boost modes. A primary circuit can have a clamping switch or at least two choke diodes. The choke diode can include "push-pull" and "L"-type configurations. A resistor can be used to dissipate energy clamped from the voltage spike. A startup circuit can be used to eliminate the in-rush current experienced during start-up. The proposed start-up schemes have been experimentally verified using a 1.6 kW, 12V/288 V prototype. Since the present invention eliminates the need to match characteristics of multiple controllers, it significantly reduces the cost associated with implementing this type of technology.

VTIP 99-011/99-012

*Low-Cost 3D Flip-Chip Packaging Technology for Integrated Power Electronics Modules*

Xingsheng Liu, Guo-Quan Lu

[US PATENT: 6,442,033](#)

Issue Date: August 27, 2002

Abstract: Resistance and parasitic inductance resulting from interconnection of semiconductor chips in power modules are reduced to negligible levels by a robust structure which completely avoids use of wire bonds through use of ball bonding and flip-chip manufacturing processes, possibly in combination with chip scale packaging and hourglass shaped stacked solder bumps of increased compliance and controlled height/shape. Turn-off voltage overshoot is reduced to about one-half or less than a comparable wire bond packaged power module. Hourglass shaped solder bumps provide increased compliance and reliability over much increased numbers of thermal cycles over wide temperature excursions.

VTIP 99-063

*Diode-Assisted Gate Turn-Off Thyristor*

Yuxin Li, Alex Q. Huang, Kevin Motto

[US PATENT: 6,426,666](#)

Issue Date: July 30, 2002

Abstract: A gate-controlled switch includes a gate turn-off thyristor in series with a diode. By using the diode in series with the GTO, the switch significantly increases the turn-off voltage that can be used for the current commutation. The utility turn-off gain and the snubberless turn-off capability are demonstrated.

## CPES Patent Portfolio

VTIP 98-029

### *Current Sensing and Current Sharing*

Xunwei Zhou, Fred C. Lee

[US PATENT: 6,414,469](#)

Issue Date: July 2, 2002

Abstract: An interleaved small-inductance buck voltage regulator (VRM) converter with the novel current sensing and sharing technology significantly improves transient response with size minimization. Specifically, two or more buck VRM modules are interleaved or connected in parallel. The resultant current waveform has a fast transient response but with reduced ripples since the ripples in the individual modules mathematically cancel one another. The result is a smooth output current waveform having spikes within an acceptable tolerance limits when for example the load increases due to a connected processor changing from "sleep" to "active" mode. A novel current sensing and sharing scheme between the individual VRMs is implemented using an RC network in each module to detect inductor current for that module. Good current sharing result can be easily achieved. Unlike peak current mode control and average current mode control, with this technology, the converter still has low output impedance and fast transient response. As a result, the VRM can be very cost-effective, high power density, high efficiency and have good transient performance.

VTIP 99-042

### *Zero Voltage Zero Current Three Level DC-DC Converter*

Peter Barbosa, Francisco Canales, Fred C. Lee

[US PATENT: 6,349,044](#)

Issue Date: February 19, 2002

Abstract: A three-level DC-to-DC converter is provided having zero-voltage and zero-current switching (ZVZCS). A flying capacitor is provided on the primary side of the converter to achieve zero voltage switching (ZVS). In addition, during freewheeling (i.e., when no power is being transferred from the primary side to the secondary side), an auxiliary power source is provided to eliminate the circulating energy and to achieve zero current switching (ZCS) for the commutation switches.

VTIP 99-038

### *Three-Phase Zero-Current-Transition (ZCT) Inverters and Rectifiers With Three Auxiliary Switches*

Yong Li, Fred C. Lee

[US PATENT: 6,337,801](#)

Issue Date: January 8, 2002

## CPES Patent Portfolio

Abstract: Zero current transition (ZCT) topologies are presented for three-phase inverters and rectifiers. Such devices are used for example in AC adjustable speed drives for so-called zero-emission vehicles (i.e., electric and hybrid combustion/electric automobiles). Compared to existing three-phase ZCT techniques, the number of auxiliary switches is reduced from six to three, while not altering the necessary device rating. Correspondingly, the number of gate-drivers for the auxiliary switches is also reduced to three. Meanwhile, the merits of the existing three-phase ZCT techniques are still retained, i.e., all the main switches and the auxiliary switches are turned on and turned off under zero-current conditions, and the independent commutation for each main switch is achieved. The desired soft-switching features are achieved. Therefore, this invention will contribute to more cost-effective, reliable, and efficient high-performance three-phase inverters and rectifiers.

### VTIP 98-044

#### *Soft-Switched Quasi-Single-Stage (QSS) Bi-Directional Inverter/Charger*

Kunrong Wang, Fred Lee

[US PATENT: 6,330,170](#)

Issue Date: December 11, 2001

Abstract: A soft-switched single-phase quasi-single-stage (QSS) bi-directional inverter/charger converts AC-DC or DC-AC. The inverter/charger comprises a push-pull inverter/rectifier on the dc-side, an isolation transformer which provides ohmic isolation and voltage scaling, two full-bridges on the ac side in cascade, a voltage clamp branch comprising a capacitive energy storage element in series with an active switch with its anti-parallel diode, a passive filter at the ac side to smooth out the high frequency switching voltage ripple at the output, and a corresponding PWM scheme to seamlessly control the converter to operate in all four quadrant operation modes in the output voltage and output current plane, and is capable of converting power in both directions.

### VTIP 98-014

#### *Single-Stage Input Current Shaping Technique with Voltage-Doubler Rectifier Front-End*

Laszlo Huber, Milan Jovanovic, Jindong Zhang, Fred Lee

[US PATENT: 6,147,882](#)

Issue Date: November 14, 2000

Abstract: A single-stage input-current-shaping (S.sup.2 ICS) converter of the present invention integrates a voltage-doubler-rectifier front-end with a DC/DC output stage. Two families of voltage-doubler S.sup.2 ICS converters are disclosed. In one family, a 2-terminal dither source is provided between a boost inductor and a common input terminal of a storage capacitor and the DC/DC output stage. The 2-terminal dither

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source includes two paths connected in parallel: a first path for charging and a second path for discharging the boost inductor at a high frequency (HF). In the other family, a 3-terminal dither source includes a third terminal coupled to a pulsating node of the DC/DC output stage. In the 3-terminal dither source, the HF charging path of the boost inductor is coupled between the boost inductor and the pulsating node of the DC/DC output stage, while the HF discharging path of the boost inductor is coupled between the boost inductor and the common input terminal of the storage capacitor and the DC/DC output stage. Due to the voltage-doubler-rectifier front-end, reduction of line-current harmonics can be achieved with a higher conversion efficiency, as compared to a corresponding S.sup.2 ICS converter with a conventional full-bridge rectifier. In addition, a converter of the present invention requires storage capacitors of a lower voltage rating and a smaller total capacitance than the conventional S.sup.2 ICS counterpart. The present invention thereby reduces the size and the cost of the power supply.

### VTIP 95-045

#### *Power Supply for Supplying AC Output Power*

Wei Chen, Fred C. Lee, Koji Nishiura\*, Tokushi Yamauchi\*, Yoshinobu Murakami\*, Minoru Maehara\* (\*MEW)

[US PATENT: 6,057,652](#)

Issue Date: May 2, 2000

Abstract: High voltage stress on the semiconductor devices at light load conditions, high total harmonic distortion (THD) of the line current, and poor crest factor (CF) of lamp current of "charge pump" electronic ballast circuits make them difficult to manufacture cost-effectively. To overcome these deficiencies, the DC bus voltage is reduced at light loads by providing a second resonance. One technique, high-frequency second-stage resonance, provides sufficient preheating at low V.sub.dc. Combined with the instant startup and the proper restart scheme, this technique can greatly reduce the maximum V.sub.dc at ignition. Another technique, low-frequency second-stage resonance, can reduce the steady state V.sub.dc at light loads, including during start-up. Consequently, high ignition voltage can be continuously impressed on the lamp without increasing V.sub.dc. Further, a diode clamping technique smooths the envelope of V.sub.a, thereby achieving near unity power factor, low THD and low CF without close-loop control.

### VTIP 97-045

#### *Gas Discharge Lamp Inverter With A Wide Input Voltage Range*

Jinrong Qian, Fred C. Lee

[US PATENT: 5,949,199](#)

Issue Date: September 7, 1999

## CPES Patent Portfolio

Abstract: A gas discharge lamp driving circuit reduces input power at start-up mode through the utilization of input power diodes and stress capacitors in parallel therewith. The circuit includes a blocking filter for filtering an AC voltage signal, and a rectifier for rectifying the signal into a DC voltage. A smoothing capacitor smooths the voltage, and an inverter, having switches, converts the DC voltage into a high frequency AC voltage. A control circuit controls the switches of the inverter to turn on and off in a feedback manner. A resonant tank is connected to the inverter, and includes a resonant capacitor and a resonant inductor. A discharge lamp is connected to the resonant tank, in parallel with the resonant capacitor. A modulation capacitor is provided for reducing a distortion of the input current to the resonant circuit. The at least two input power diodes and the stress capacitors are connected between the rectifier and the smoothing capacitor, such that a discharge time of the stress capacitors delays a turn-on time of the input power diodes, to reduce input power at start-up.

VTIP 96-031

### *Method and Apparatus For Automatic Average Current Mode Controlled Power Factor Correction Without Input Voltage Sensing*

Jay Rajagopalan, Paolo Nora, Fred C. Lee

[US PATENT: 5,920,471](#)

Issue Date: July 6, 1999

Abstract: A method for preparing power factor control integrated circuits which generate linear pulse width modulation (PWM) waveforms is presented. The method of pulse width modulation waveform generation involves providing a capacitor; fast charging the capacitor; and controlling a discharge rate of the capacitor to ensure a constant switching period and a linear PWM waveform. The method is applicable for any single-phase ac/dc converter topology that performs power factor correction. Unlike conventional techniques which utilize three feedback loops, the method of the present invention reduces the total number of feedback loops to two, eliminates input voltage sensing and achieves the same objective. This method results in significant integrated circuit simplification, such as elimination of multiplier, squarer and divider circuits in the control integrated circuit and reduces the cost of the integrated circuit.

VTIP 96-093

### *Discharge Lamp Driving Circuit Having Resonant Circuit Defining Two Resonance Modes*

Jinrong Qian, Fred C. Lee, Tokushi Yamauchi (MEW)

[US PATENT: 5,914,572](#)

Issue Date: June 22, 1999

## CPES Patent Portfolio

Abstract: An improved discharge lamp driving circuit of a charge-pump type capable of suppressing a ripple in an envelop of a lamp current at the time of dimming the lamp or at a low environmental temperature. The circuit includes an inverter having switching elements Q1 and Q2 for converting a voltage across a smoothing capacitor  $C_e$  into a high frequency power which is applied through a resonant circuit to the discharge lamp  $L_d$ . A capacitor  $C_{in}$  is connected to one end of the resonant circuit to vary a DC voltage of the output of the rectifier in accordance with a varying instantaneous value of the high frequency current or voltage appearing in the resonant circuit. A control circuit is provided to give a control signal for alternately turning on and off the switching elements Q1 and Q2. A feedback circuit FB is provided to modulate the control signal within a permissible range given to the control circuit in such a manner as to adjust the timing of turning on and off the switching elements Q1 and Q2 in a feedback manner based upon a lamp current detected by a current sensor SI, for reducing the ripple in the lamp current. A mixer MX is included to compensate for the lamp current in consideration of a dimmer signal Dim of dimming the lamp in order to suppress the ripple which would otherwise increase due to the dimming of the lamp.

### VTIP 93-081

#### *Soft Switched Three-Phase Boost Rectifiers and Voltage Source Inverters*

Yimin Jiang, Fred C. Lee

[US PATENT: 5,633,793](#)

Issue Date: May 27, 1997

Abstract: A boost rectifier is provided with an ultra high speed diode in its direct current rail to reduce diode reverse recovery loss with or without implementing a soft switching technique. Full zero-voltage-transition (ZVT) as well as zero-current-transition (ZCT) may also be achieved by adding a simple auxiliary network across the DC rail which operates only during the short turn-on transients of the bridge switches. Similarly, a simple, inexpensive auxiliary circuit can be added to the DC rail of a conventional voltage source inverter shown to implement both ZVT and ZCT.

### VTIP 94-029

#### *Zero-Voltage-Transition (ZVT) 3-Phase PWM Voltage Link Converters*

Hengchun Mao, Fred C. Lee

[US PATENT: 5,574,636](#)

Issue Date: November 12, 1996

Abstract: An improved zero voltage transition (ZVT) pulse width modulation (PWM) link converter is provided which introduces a space vector modulation scheme and an auxiliary circuit which includes a commutation power supply or special switch arrangement used to discharge resonant inductor currents to zero and to recover

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commutation energy. In an alternate embodiment, an improved ZVT PWM link converter provides an auxiliary switch for each main switch in the converter to achieve ZVT. The novel ZVT converters provide zero-voltage switching without increasing switching action of the main switches. In this way, the advantages of PWM control is maintained. Conduction loss, turn-off losses, and voltage stress of the main switches are the same as in conventional PWM converters, but the dominant turn-on losses are eliminated, so total power losses are minimized.

### VTIP 93-065

#### *Damped EMI Input Filter Power Factor Correction Circuits*

Vlatko Vlatkovic, Dusan Borojevic, Fred C. Lee

[US PATENT: 5,530,396](#)

Issue Date: June 25, 1996

Abstract: An active damping circuit for an electromagnetic interference (EMI) filter for power factor correction (PFC) circuit is provided which simulates a line damping impedance which actively varies according to sensed line current. The active damping circuit comprises an nth-order, Cauer-Chebyshev, low-pass filter having input series damping impedance ( $Z_{sub.d}$ ) simulated with a power operational amplifier and high-frequency isolation transformer. The simulated damping impedance offers greatly reduced size and power dissipation as compared to prior art passive schemes which typically require large impedance components for damping. A passive damping circuit is also shown which involves providing an alternate inductive current path in parallel with a damping resistor whereby lower frequency currents are diverted through the alternate current path and higher frequency currents continue to flow through the damping resistor. In this manner, the damping action of the damping resistor is attenuated for lower frequencies but remains unaffected for higher frequencies.

### VTIP 93-072

#### *Zero-Current Transition PWM Converters*

Guichao Hua, Fred C. Lee

[US PATENT: 5,486,752](#)

Issue Date: January 23, 1996

Abstract: A zero-current transition pulse-width modulated (ZCT-PWM) d.c.-d.c. converter allows minority-carrier semiconductor devices such as, for example, bipolar junction transistors (BJTs), insulated gate bipolar transistors (IGBTs), MOSFET controlled thyristors (MCTs), and gate turn-off thyristors (GTOs), to be used as switches for high-power, high frequency applications. The ZCT-PWM converter comprises a shunt resonant branch inserted into a conventional PWM converter circuit. The resonant branch comprises a resonant inductor ( $L_r$ ), a resonant capacitor ( $C_r$ ), an auxiliary switch ( $S_1$ ), and an auxiliary diode ( $D_1$ ). The resonant branch is only

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active during a relatively short switching time in order to create a zero-current switch condition for the main pulse-modulating switch (S) without substantially increasing voltage or current stresses.

### VTIP 90-073

#### *Soft-Switching PWM Converters*

Guichao Hua, Fred C. Lee

[US PATENT: 5,442,540](#)

Issue Date: August 15, 1995

Abstract: A full-bridge zero-voltage-switching pulse-width-modulated converter employs a saturable reactor in place of the linear inductor in order to reduce current stress on the active switches, reduce voltage stress on the rectifier diodes, and reduce secondary parasitic ringing. The zero-current-switching full-bridge pulse-width-modulated converter embodiment of the invention contemplates the provision of active switches that are zero-current-switched and passive switches, such as diode switches, that are zero-voltage-switched.

### VTIP 93-016

#### *Zero-Voltage-Switched, Three-Phase PWM Rectifier Inverter Circuit*

Vlatko Vlatkovic, Fred C. Lee, Dusan Borojevic

[US PATENT: 5,432,695](#)

Issue Date: July 11, 1995

Abstract: A novel switching rectifier circuit that combines the conventional three-phase, 6-stepped PWM rectifier/inverter circuit with a simple, low-power switch commutation circuit to provide zero-voltage turn-on for the switches, and soft turn-off for the diodes. The main features of the new circuit include elimination of switching losses on the power switches and reverse recovery problems on the diodes, elimination of the need for any snubbers in the three-phase bridge, possibility of use of slower diodes in the power bridge, constant frequency operation, and no increase in component current and voltage stresses over the conventional PWM rectifier.

### VTIP 91-028

#### *Zero-Voltage-Transition Pulse-Width-Modulated Converters*

Guichao Hua, Fred C. Lee

[US PATENT: 5,418,704](#)

Issue Date: May 23, 1995

Abstract: To date, soft-switching techniques applied to the PWM converters, with the exception of a few isolated cases, are subjected to either high switch voltage stresses or high switch current stresses, or both. This invention presents a new class of zero-voltage-transition PWM converters, where both the transistor and the rectifier operate



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with zero-voltage switching, and are subjected to minimum voltage and current stresses. Breadboarded converters are constructed to verify the novelty of the proposed new family of converters.

### VTIP 91-025

#### *Zero-Voltage-Switched, Three-Phase Pulse-Width-Modulating Switching Rectifier With Power Factor Correction*

Vlatko Vlatkovic, Dushan Boroyevich, Fred C. Lee

[US PATENT: 5,329,439](#)

Issue Date: July 12, 1994

Abstract: A three-phase, pulse-width-modulated, switching rectifier, with zero-voltage-switching.

### VTIP 91-011

#### *Novel Zero-Voltage-Switching Family of Isolated Converters*

Richard Farrington, Milan Jovanovic, Fred C. Lee

[US PATENT: 5,325,283](#)

Issue Date: June 28, 1994

Abstract: An isolated zero-voltage-switching converter in which the magnetizing inductance of the isolating transformer is a resonant element and an open circuit is provided on the secondary side of the transformer during the time interval when both primary switches are off. When the secondary of the transformer is open, the magnetizing inductance is in series with the capacitances of the primary switches, thus forming a resonant circuit.

### VTIP 91-029

#### *Zero-Voltage Transition PWM Converters*

Guichao Hua, Fred C. Lee

[US PATENT: 5,262,930](#)

Issue Date: November 16, 1993

Abstract: A pulse-width-modulated, quasi-resonant, d.c. to d.c. converter that has an auxiliary switch that periodically kills the resonance.

### VTIP 89-032

#### *Constant Frequency Zero-Voltage-Switching Multi-Resonant Converter*

Milan Jovanovic, Richard Farrington, Fred C. Lee

[US PATENT: 4,931,716](#)

Issue Date: June 5, 1990

Abstract: A zero-voltage multi-resonant converter that operates at constant frequency. In the zero-voltage multi-resonant converter, the resonant circuit is formed

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in a .pi.-network with resonant capacitors connected in parallel with the switches. In practicing the present invention, certain rules are applied to derive a CF ZVS-MRC from a PWM converter. In particular, one resonant capacitor is placed in parallel with the active switch, which may be either uni-directional or bi-directional, the rectifying switch is replaced by another active switch, which may also be uni-directional or bi-directional, another resonant capacitor is placed in parallel with the other active switch, and an inductor is inserted in the loop containing the two switches. This loop can also contain voltage sources and filter or blocking capacitors.

### VTIP 80-018

#### *Multi-Loop Control for Quasi-Resonant Converters*

Raymond B. Ridley, Fred C. Lee

[US PATENT: 4,866,367](#)

Issue Date: September 12, 1989

Abstract: A multi-loop controller for controlling a quasi-resonant converter having a power switch, a filter inductor and an output voltage. The controller includes a sensor circuit for sensing the output voltage of the converter. A detector monitors the filter inductor current of the converter. The output voltage is compared with a known reference voltage to develop a control error voltage when the output voltage exceeds the reference voltage. A comparing circuit then compares the inductor current with the control error voltage and produces a control signal when a predetermination relationship has been detected. Finally, an activating circuit responsive to the control signal turns the power switch on.

### VTIP 80-017

#### *Half-Bridge Zero-Voltage Switched Multi-Resonant Converters*

Wojciech A. Tabisz, Fred C. Lee, Milan M. Jovanovic

[US PATENT: 4,860,184](#)

Issue Date: August 22, 1989

Abstract: A half-bridge zero-voltage-switched multi-resonant converter. The converter basically comprises a device for converting an input voltage signal to a DC output signal to be imposed across a load. The device includes input terminals for receiving the input signal and output terminals for imposing the DC output signal across the load. Serially connected first and second switching assemblies are connected in parallel across the input terminals. Each of the first and second switching assemblies includes a transistor switch, a diode and a capacitor all arranged in parallel. The device further includes a transformer having a primary winding and serially connected first and second secondary windings. A first rectifier in parallel with a first resonant capacitor is used to connect the first secondary winding across the output terminals. Circuitry is provided for connecting the primary winding of the transformer

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to the input terminals and to the serial connection between the first and second switching assemblies. In order to complete the zero-voltage-switched multi-resonant converter for off-line use, a resonant circuit is formed with the first and second resonant capacitors and the total inductance of the primary winding of the transformer.

### VTIP 86-007

#### *Zero-Voltage-Switched Multi-Resonant Converters Including the Buck And Forward Type*

Wojciech A. Tabisz, Fred C. Lee

[US PATENT: 4,857,822](#)

Issue Date: August 15, 1989

Abstract: A multi-resonant-switching network that operates under switching conditions that are favorable to both the active switch and the diode that constitute the switch. In a zero-current multi-resonant switch, the resonant circuit is formed in a T-network with resonant inductors in series with the switching devices. In a zero-voltage multi-resonant switch, the resonant circuit is formed in a .pi.-network with resonant capacitors connected in parallel with the switch. In this way, the two networks are dual. During operation of a multi-resonant converter, a multi-resonant switches forms three different resonant circuits depending on whether the active switch and diode are open or closed. This results in operation of the converter with three different resonant stages in one cycle of operation. In practicing the present invention, certain rules are applied to derive a ZVS-MRC from a PWM converter. In particular, one resonant capacitor is placed in parallel with the active switch, which may be either uni-directional or bi-directional, another resonant capacitor is placed in parallel with the rectifying diode, and an inductor is inserted in the loop containing the switch and the diode. This loop can also contain voltage sources and filter or blocking capacitors. Improvement in the operation of ZVS-MRCs is obtained with synchronous rectification which is achieved by replacing rectifying diodes in a DC/DC converter with active devices, called synchronous rectifiers.

### VTIP 88-029

#### *Non-Destructive Tester For Transistors*

Grant Carpenter, Fred C. Lee, Dan Y. Chen

[US PATENT: 4,851,769](#)

Issue Date: July 25, 1989

Abstract: A non-destructive reverse-bias second breakdown tester for testing semiconductor devices such as transistors and thyristors that have a base-collector-emitter configuration. The tester basically comprises a socket for holding the device under test. A base drive provides a drive current to the base of the device under test.

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A collector supply provides a collector current to the device under test. A current diverter diverts current away from the device under test when the device under test experiences reverse-bias second breakdown. The diverter includes first, second and third switches arranged in series. A diode diverter is connected to the current supply and the third switch. A detector produces a first signal at the onset of reverse-bias second breakdown in the device under test. In response to the first signal, the first, second and third switches are activated in seriatim. The activation of all of the first, second and third switches causes the current applied to said device under test to be diverted through said diode diverter and the first, second and third switches.

### VTIP 88-003

#### *Dc-To-Dc Converters Using Multi-Resonant Switches*

Wojciech A. Tabisz, Fred C. Lee

[US PATENT: 4,841,220](#)

Issue Date: June 20, 1989

Abstract: A generalized multi-resonant switch that combines current-mode and voltage-mode resonant switches. Application of the multi-resonant switch in zero-voltage switched multi-resonant converters results in reduction of the voltage stress to the switching transistor, increase of the load range and reduction of the switching frequency bandwidth. Each embodiment of the multi-resonant converter includes a multi-resonant switch having an active switch, a passive switch and reactive components for causing the active and passive switches to operate in a multi-resonant manner.

### VTIP 80-012

#### *Resonant Converters with Secondary-Side Resonance*

Kwang-Hwa Liu, Fred C. Lee

[US PATENT: 4,785,387](#)

Issue Date: November 15, 1988

Abstract: A family of quasi-resonant converters is disclosed as comprising a voltage source, a transformer having primary and secondary windings, and a switch for periodically coupling the voltage source to the primary winding, whereby a charging current appears on the secondary winding. The transformer exhibits a characteristic leakage inductance. A capacitor exhibiting a characteristic capacitance is coupled to the secondary winding to form a resonant circuit including the leakage inductance and the capacitor. The secondary winding is coupled to apply the charging current to the capacitor. A rectifying circuit couples the capacitor to a load, whereby the voltage stored in the capacitor is delivered to the load. The capacitor is directly connected to the secondary winding and to the rectifying circuit to permit positive and negative

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going voltages to be stored therein, whereby magnetic flux within the core of the transformer is dissipated and the transformer magnetically reset.

### VTIP 80-015

#### *Zero-Voltage Switching Quasi-Resonant Converters*

Kwang-Hwa Liu, Fred C. Lee

[US PATENT: 4,720,668](#)

Issue Date: January 19, 1988

Abstract: A quasi-resonant converter is disclosed as comprising a power source, a load and a resonant switch circuit for periodically connecting the power source to the load. The resonant switch circuit includes a switch for connecting the power source to the load and for disconnecting the power source from the load, and a resonant circuit comprised of a resonant capacitor and a resonant inductor. The switch is operated at a switching frequency in excess of 1 MHz and in the order of 10 to 20 MHz or greater. The resonant circuit is connected to the switch to impose thereon a voltage waveform as developed across the resonant capacitor. The resonant capacitor and the resonant inductor have respective impedances selected to shape the voltage waveform such that a zero-voltage condition is imposed upon the switch when it is disposed to its on state, whereby the parasitic capacitive losses associated with the switch are eliminated.

### VTIP 80-014

#### *Zero-Current Switching Quasi-Resonant Converters Operating in a Full-Wave Mode*

Kwang-Hwa Liu, Fred C. Lee

[US PATENT: 4,720,667](#)

Issue Date: January 19, 1988

Abstract: A family of quasi-resonant converters for providing regulated power is disclosed as comprising a voltage source, a load and a resonant switch circuit, for periodically connecting the voltage source to the load. The resonant switch circuit includes a switch, and a resonant circuit comprised of a resonant capacitor and a resonant inductor. The switch is actuated to its first state to permit a current flow in a first direction from the voltage source to the load and to block a current flow in a second, opposite direction, and deactuated to a second state to permit a current flow in the second direction from the load to the voltage source and to block the current flow in the first direction, whereby the quasi-resonant converter is operative in a full-wave mode. More specifically, the switch in its first state couples the resonant capacitor and the resonant inductor together to form a resonant switch circuit. The impedances of the resonant capacitor and the resonant inductor are selected to establish a resonating current waveform on the resonant inductor to apply zero-current conditions to the switch at turn on and turn off.

