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Inventor(s) Paduvalli; Vikas et al.

ELECTRICAL ASSEMBLIES INCLUDING MAGNETIC DEVICES

Abstract

An electrical assembly includes a first substrate, a second substrate, and a magnetic device disposed between the first substrate and the second substrate. The magnetic device includes (1) a magnetic core, (2) a first primary winding extending through the magnetic core and electrically coupling the first substrate to the second substrate, (3) a second primary winding extending through the magnetic core and electrically coupling the first substrate to the second substrate, (4) a first secondary winding wound around at least a portion of the magnetic core, and (5) a second secondary winding wound around at least a portion of the magnetic core. The electrical assembly further includes one or more electrical conductors on the first substrate electrically coupling the first secondary winding in series with the second secondary winding.

Inventors: **Paduvalli; Vikas (San Jose, CA), Ikriannikov; Alexandr (San Jose, CA)**

Applicant: **Analog Devices, Inc.** (Wilmington, MA)

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Background/Summary

BACKGROUND

[0001] Switching power converters are widely used in electronic devices, such as to provide a regulated electric power source. A switching power converter is configured such that its solid-state power switching devices do not continuously operate in their active states; instead, the power switching devices repeatedly switch between their on-states and off-states. Switching power converters commonly include one or more inductors for energy storage.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] FIG. **1** is a schematic diagram of an electrical assembly including a magnetic device, according to an embodiment.

[0003] FIG. **2** is a top plan view of a magnetic device, according to an embodiment.

[0004] FIG. **3** is a front elevational view of the FIG. **2** magnetic device.

[0005] FIG. **4** is a bottom plan view of the FIG. **2** magnetic device.

[0006] FIG. **5** is a side elevational view of the FIG. **2** magnetic device.

[0007] FIG. **6** is a cross-sectional view of the FIG. **2** magnetic device taken along line **6**A-**6**A of FIG. **2**.

[0008] FIG. **7** is a top plan view of an embodiment of the FIG. **2** magnetic device where a magnetic core forms two gaps.

[0009] FIG. **8** is a top plan view of another embodiment of the FIG. **2** magnetic device where a magnetic core forms two gaps.

[0010] FIG. **9** is a front elevational view of an electrical assembly including an instance of the FIG. **2** magnetic device, according to an embodiment.

[0011] FIG. **10** is a side elevational view of the FIG. **9** electrical assembly.

[0012] FIG. **11** is top plan view of the FIG. **9** electrical assembly.

[0013] FIG. **12** is an electrical schematic diagram of a multi-phase switching power converter at least partially formed by elements of the FIG. **9** electrical assembly.

[0014] FIG. **13** is a front elevational view of an alternate embodiment of the FIG. **9** electrical assembly.

[0015] FIG. **14** is a side elevational view of the FIG. **13** electrical assembly.

[0016] FIG. **15** is top plan view of the FIG. **13** electrical assembly.

[0017] FIG. **16** is a top plan view of an alternate embodiment of the FIG. **2** magnetic device.

[0018] FIG. **17** is a front elevational view of the FIG. **16** magnetic device.

[0019] FIG. **18** is a side elevational view of the FIG. **16** magnetic device.

[0020] FIG. **19** is a bottom plan view of the FIG. **16** magnetic device.

[0021] FIG. **20** is a top plan view of an alternate embodiment of the FIG. **16** magnetic device further including ground conductors.

[0022] FIG. **21** is a front elevational view of the FIG. **20** magnetic device.

[0023] FIG. **22** is a side elevational view of the FIG. **20** magnetic device.

[0024] FIG. **23** is a bottom elevational view of the FIG. **20** magnetic device.

[0025] FIG. **24** is a cross-sectional view of the FIG. **20** magnetic device taken along line **24**A-**24**A of FIG. **20**.

[0026] FIG. **25** is a front elevational view of an alternate embodiment of the FIG. **9** electrical assembly including the FIG. **20** magnetic device in place of the FIG. **2** magnetic device.

[0027] FIG. **26** is schematic diagram of an alternate embodiment of the FIG. **12** multi-phase switching power converter including the FIG. **20** magnetic device in place of the FIG. **2** magnetic device.

[0028] FIG. **27** is a top plan view of another alternate embodiment of the FIG. **16** magnetic device further including ground conductors.
[0029] FIG. **28** is a front elevational view of the FIG. **27** magnetic device.
[0030] FIG. **29** is a side elevational view of the FIG. **27** magnetic device.
[0031] FIG. **30** is a cross-sectional view of the FIG. **27** magnetic device taken along line **30**A-**30**A of FIG. **27**.
[0032] FIG. **31** is a bottom plan view of the FIG. **27** magnetic device.
[0033] FIG. **32** is a top plan view of an alternate embodiment of the FIG. **2** magnetic device including two additional winding sets.
[0034] FIG. **33** is a front elevational view of the FIG. **32** magnetic device.
[0035] FIG. **34** is a side elevational view of the FIG. **32** magnetic device.
[0036] FIG. **35** is a bottom plan view of the FIG. **32** magnetic device.
[0037] FIG. **36** is a cross-sectional view of the FIG. **32** magnetic device taken along line **36**A-**36**A of FIG. **32**.
[0038] FIG. **37** is a top plan view of an alternate embodiment of the FIG. **2** magnetic device including only a single winding set.
[0039] FIG. **38** is a front elevational view of the FIG. **37** magnetic device.
[0040] FIG. **39** is a side elevational view of the FIG. **37** magnetic device.
[0041] FIG. **40** is a bottom plan view of the FIG. **37** magnetic device.
[0042] FIG. **41** is a front elevational view of an alternate embodiment of the FIG. **9** electrical assembly including two instances of the FIG. **37** magnetic device in place of the FIG. **2** magnetic device.
[0043] FIG. **42** is a top plan view of the FIG. **41** electrical assembly.
[0044] FIG. **43** is a front elevational view of an alternate embodiment of the FIG. **41** electrical assembly including two substrates in place of a single common substrate.
[0045] FIG. **44** is a top plan view of the FIG. **43** electrical assembly.
[0046] FIG. **45** is a bottom plan view of the FIG. **43** electrical assembly.
[0047] FIG. **46** is an electrical schematic diagram of a multi-phase switching power converter at least partially formed by elements of the FIG. **43** electrical assembly.
[0048] FIG. **47** is a top plan view of an alternate embodiment of the FIG. **20** magnetic device with primary windings forming two turns each.
[0049] FIG. **48** is a front elevational view of the FIG. **47** magnetic device.
[0050] FIG. **49** is a side elevational view of the FIG. **47** magnetic device.
[0051] FIG. **50** is a bottom plan view of the FIG. **47** magnetic device.
[0052] FIG. **51** is a back elevational view of the FIG. **47** magnetic device.
[0053] FIG. **52** is a top plan view of an alternate embodiment of the FIG. **47** magnetic device that is scalable in two directions.
[0054] FIG. **53** is a front elevational view of the FIG. **52** magnetic device.
[0055] FIG. **54** is a bottom plan view of the FIG. **52** magnetic device.
[0056] FIG. **55** is a front elevational view of an alternate embodiment of the FIG. **2** magnetic device where winding ends are offset from magnetic core outer surfaces.
[0057] FIG. **56** is a side elevational view of the FIG. **55** magnetic device.
[0058] FIG. **57** is a side elevational view of the FIG. **55** magnetic device opposite of the side elevational view of FIG. **56**.
[0059] FIG. **58** is a front elevational view of an alternate embodiment of the FIG. **9** electrical assembly including the FIG. **55** magnetic device in place of the FIG. **2** magnetic device.
[0060] FIG. **59** is a top plan view of an alternate embodiment of the FIG. **2** magnetic device where secondary winding ends terminate on a front outer surface of a magnetic core instead of a top outer surface of the magnetic core.
[0061] FIG. **60** is a front elevational view of the FIG. **59** magnetic device.

[0062] FIG. **61** is a bottom plan view of the FIG. **59** magnetic device.
[0063] FIG. **62** is a side elevational view of the FIG. **59** magnetic device.
[0064] FIG. **63** is a front elevational view of an alternate embodiment of the FIG. **9** electrical assembly including the FIG. **59** magnetic device in place of the FIG. **2** magnetic device.
[0065] FIG. **64** is a side elevational view of the FIG. **63** electrical assembly.
[0066] FIG. **65** is a top plan view of a magnetic device where primary windings terminate on a different surface than secondary windings, according to an embodiment.
[0067] FIG. **66** is a front elevational view of the FIG. **65** magnetic device.
[0068] FIG. **67** is a bottom plan view of the FIG. **65** magnetic device.
[0069] FIG. **68** is a side elevational view of the FIG. **65** magnetic device
[0070] FIG. **69** is a side elevational view of the FIG. **65** magnetic device opposite of the FIG. **68** side elevational view.
[0071] FIG. **70** is a cross-sectional view of the FIG. **65** magnetic device taken along line **70**A-**70**A of FIG. **65**.
[0072] FIG. **71** is a front elevational view of an electrical assembly including the FIG. **65** magnetic device, according to an embodiment.
[0073] FIG. **72** is a side elevational view of the FIG. **71** electrical assembly.
[0074] FIG. **73** is a top plan view of the FIG. **71** electrical assembly.
[0075] FIG. **74** is an electrical schematic diagram of a multi-phase switching power converter at least partially formed by elements of the FIG. **71** electrical assembly.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0076] Some switching power converters include a plurality of phases, where each phase includes a respective switching stage and a respective inductor. Such switching power converters may be referred to as multi-phase switching power converters. While not required, the respective switching stage of each phase typically switches out-of-phase with respect to the respective switching stage of each other phase. The inductors of a multi-phase switching power converter may be magnetically coupled to realize significant benefits, such as lower ripple current magnitude and/or faster transient response, than an otherwise similar multi-phase switching power converter without magnetic coupling of its inductors. Alternately, phases of a multi-phase switching power converter may be electrically coupled by replacing each inductor with a primary winding, magnetically coupled a respective secondary winding with each primary winding, and electrically coupling the secondary windings in series. Such electrical coupling of phases may also lower ripple current magnitude and/or improve transient response, albeit not to the degree that is possible with magnetic coupling of phases. The magnetic coupling of phases can also be combined with electrical coupling of phases; for example, two of four phase magnetically coupled inductors can be electrically coupled to each other.
[0077] Electrical assemblies including switching power converters may include more than one substrate, such as more than one printed circuit board (PCB). For example, switching stages of a switching power converter may be located on one substrate, and output capacitors of the switching power converter may be located on a second substrate. The first and second substrates are electrically connected, for example, by metallic pins joining the substrates.
[0078] Disclosed herein are electrical assemblies including magnetic devices which significantly advance the state of the art of multi-phase switching power converters with electrical coupling of phases. Particular embodiments include a magnetic device sandwiched between a first substrate and a second substrate, such as between a first and a second PCB. The magnetic device includes a plurality primary windings extending through a magnetic core of the magnetic device, and each primary winding electrically couples the first substrate to the second substrate, such that one end of each primary winding is electrically coupled to the first substrate and an opposing end of the primary winding is electrically coupled to the second substrate. Additionally, the magnetic device includes a respective secondary winding magnetically coupled to each primary winding, and

opposing ends of each secondary winding are electrically coupled to the first substrate. The secondary windings are electrically coupled in series by one or more electrical conductors on the first substrate.
[0079] Furthermore, some embodiments include a plurality of magnetic devices, where each magnetic device is disposed between a first substrate and a second substrate. Each magnetic device includes a primary winding extending through a magnetic core of the magnetic device and electrically coupling the first substrate to the second substrate. Each magnetic device further includes a secondary winding magnetically coupled to the primary winding of the magnetic device, and opposing ends of the secondary winding are electrically coupled to the first substrate. The secondary windings of the magnetic devices are electrically coupled in series by one or more electrical conductors on the first substrate.
[0080] Additionally, certain embodiments include a plurality of magnetic devices, where each magnetic device is disposed between a common substrate and a respective additional substrate. Each magnetic device includes a primary winding extending through a magnetic core of the magnetic and device and electrically coupling the first substrate to the respective additional substrate of the magnetic device. Each magnetic device further includes a secondary winding magnetically coupled to the primary winding of the magnetic device, and opposing ends of the secondary winding are electrically coupled to the first substrate. The secondary windings of the magnetic devices are electrically coupled in series by one or more electrical conductors on the first substrate.
[0081] The new electrical assemblies may achieve significant advantages that may not be realized by conventional approaches. For example, in particular embodiments, the primary windings form electrical connections between substrates, thereby reducing, or even eliminating, the need for additional electrical conductors to electrically couple the primary windings to each substrate or additional conductors to pass the current between the substrates, which promotes low electrical resistance in primary winding connections. Low electrical resistance in primary winding connections, in turn, promotes low power loss, low resistive heating, and high efficiency. Additionally, in particular embodiments, the secondary windings terminate on a common plane, e.g., on the surface of a common substrate, which promotes ease of electrical connections to the secondary windings and promotes planarity of the magnetic device on a side of the magnetic device opposite of a side where the secondary windings terminate. Furthermore, some embodiments include standard geometry magnetic core elements that do not need to be redesigned to accommodate the secondary windings, such as two E-cores or an E-core and I-core, which promotes ease of manufacturing, low cost, and ease of sourcing the magnetic core elements. Moreover, particular embodiments are scalable, i.e., they can be configured to support any number of phases. Additionally, particular embodiments have a low profile, and some embodiments have small air gaps, or even no air gaps, which helps minimize potential for radiated electromagnetic interference (EMI) with other circuitry. Furthermore, particular embodiments implement electrical coupling of phases, which promotes fast transient response and/or low ripple current magnitude.
[0082] FIG. **1** is schematic diagram of an electrical assembly **100**, which is one embodiment of the new electrical assemblies disclosed herein. Electrical assembly **100** includes a first substrate **102**, a second substrate **104**, and a magnetic device **106**. In some embodiments, each of first substrate **102** and second substrate **104** is a respective PCB. First substrate **102** is separated from second substrate **104** is a direction **108**, and magnetic device **106** is disposed between first substrate **102** and second substrate **104** in direction **108**. Accordingly, magnetic device **106** is sandwiched between first substrate **102** and second substrate **104**.
[0083] Magnetic device **106** includes a magnetic core **110** and N winding sets **112**, where N is an integer greater than or equal to one. In this document, specific instances of an item may be referred to by use of a numeral in parentheses (e.g. winding set **112**(**1**)) while numerals without parentheses refer to any such item (e.g. winding sets **112**). While FIG. **1** illustrates N being equal to at least

three, it is understood that N could alternately be equal to two or equal to one. Each winding set **112** includes a respective primary winding **114** and a respective secondary winding **116**. The primary winding **114** and the secondary winding **116** of each winding set **112** are magnetically coupled. For example, primary winding **114**(**1**) is magnetically coupled with secondary winding **116**(**1**), and primary winding **114**(**2**) is magnetically coupled with secondary winding **116**(**2**). The windings of each winding set **112** are ideally not magnetically coupled with windings of each other winding set **112**. For example, the windings of winding set **112**(**1**) are ideally not magnetically coupled with the windings of winding set **112**(**2**). However, there usually will be at least some magnetic coupling between windings of two or more winding sets **112** due to the winding sets **112** sharing a common magnetic core **110**.

[0084] Each primary winding **114** extends through magnetic core **110** in first direction **108**, and each primary winding **114** electrically couples first substrate **102** to second substrate **104**. Each secondary winding **116** is wound around at least a portion of magnetic core **110**, and opposing ends **118** and **120** of each secondary winding **116** are electrically coupled to first substrate **102**. Only one instance of secondary winding **116** ends **118** and **120** are labeled in FIG. **1** for illustrative clarity. Secondary windings **116** are electrically coupled in series by one or more electrical conductors **122** on first substrate **102**. While not required, electrical assembly **100** will commonly include additional elements, such as switching stages and capacitors, which cooperate with magnetic device **110** to collectively form a multi-phase switching power converter. While FIG. **1** illustrates winding sets **112** being separated from each other in a direction **124** that is orthogonal to direction **108**, winding sets **112** could alternately and/or additionally be separated from each in a third direction that is orthogonal to each of directions **108** and **124**, i.e., in a direction that is normal to the page of FIG. **1**.

[0085] Discussed below are several example of embodiments of magnetic device **106** as well as several example embodiments of electrical assembly **100**. It is understood, though, that magnetic device **106** and electrical assembly **100** are not limited to the example embodiments discussed below.

[0086] FIGS. **2-6** collectively illustrate a magnetic device **200**, where magnetic device **200** is one possible embodiment of magnetic device **106** of FIG. **1** where N is equal to two. FIG. **2** is a top plan view of magnetic device **200**, FIG. **3** is a front elevational view of magnetic device **200**, FIG. **4** is a bottom plan view of magnetic device **200**, FIG. **5** is a side elevational view of magnetic device **200**, and FIG. **6** is a cross-sectional view of magnetic device **200** taken along line **6**A-**6**A of FIG. **2**. The terms “top,” bottom,” “front,” and “side” in this document are used for convenience and do not require any particular orientation of their associated elements. For example, the top of magnetic device **200** illustrated in FIG. **2** may be considered a side of magnetic device **200** in applications where magnetic device **200** is rotated by 90 degrees relative to its orientation in FIGS. **2-6**. FIGS. **2-6** collectively illustrate coordinate axes including a first direction **202**, a second direction **204**, and a third direction **206**, where the second direction **204** is orthogonal to the first direction **202**, and the third direction **206** is orthogonal to each of the first direction **202** and the second direction **204**.

[0087] Magnetic device **200** includes a magnetic core **208**, a first primary winding **210**, a second primary winding **212**, a first secondary winding **214**, and a second secondary winding **216**. Magnetic core **208** is an embodiment of magnetic core **110** (FIG. **1**), each of first primary winding **210** and second primary winding **212** is an embodiment of a primary winding **114** instance (FIG. **1**), and each of first secondary winding **214** and second secondary winding **216** is an embodiment of a secondary winding **116** instance (FIG. **1**). First primary winding **210** has opposing ends **218** and **220**, and second primary winding **212** has opposing ends **222** and **224**. First secondary winding **214** has opposing ends **226** and **228**, and second secondary winding **216** has opposing ends **230** and **232**.

[0088] Magnetic core **208** forms a first winding window **234** and a second winding window **236** extending through magnetic core **208** in first direction **202**. First winding window **234** and second winding window **236** are separated from each other in second direction **204**. First primary winding **210** is wound through first winding window **234** such that first primary winding **210** extends through magnetic core **208** in first direction **202**. Additionally, first primary winding **210** is wound through first winding window **234** and around a portion of magnetic core **208** such that (i) end **218** of first primary winding **210** is on a top outer surface **238** of magnetic core **208** and (ii) end **220** of first primary winding **210** is on a bottom outer surface **240** of magnetic core **208**, where bottom outer surface **240** is opposite of top outer surface **238**. Similarly, second primary winding **212** is wound through second winding window **236** and around a portion of magnetic core **208** that (i) end **222** of second primary winding **212** is on top outer surface **238** of magnetic core **208** and (ii) end **224** of second primary winding **212** is on bottom outer surface **240** of magnetic core **208**.

[0089] First secondary winding **214** is wound through first winding window **234**, along bottom outer surface **240** of magnetic core **208**, and along a front outer surface **242** of magnetic core **208** such that of end **226** and end **228** of first secondary winding **214** are each on top outer surface **238** of magnetic core **208**. Front outer surface **242** of magnetic core **208** joins top outer surface **238** of magnetic core **208** and bottom outer surface **240** of magnetic core **208** in first direction **202**. Additionally, second secondary winding **216** is wound through second winding window **236**, along bottom outer surface **240** of magnetic core **208**, and along front outer surface **242** of magnetic core **208** such that of end **230** and end **232** of second secondary winding **216** are each on top outer surface **238** of magnetic core **208**. First secondary winding **214** is separated from first primary winding **210** in third direction **206** within first winding window **234**, and second secondary winding **216** is separated from second primary winding **212** in third direction **206** within second winding window **236**.

[0090] Magnetic core **208** is formed, for example, of a ferrite magnetic material. Particular embodiments of magnetic core **208** include (i) a first gap in series with a magnetic flux path in magnetic core **208** magnetically coupling first primary winding **210** and first secondary winding **214** and (ii) a second gap in series with a magnetic flux path in magnetic core **208** magnetically coupling second primary winding **212** and second secondary winding **216**. For example, FIG. **7** is a top plan view of a magnetic device **700**, where magnetic device **700** is an embodiment of magnetic device **200** (FIGS. **2-6**) where magnetic core **208** forms a first gap **744** and a second gap **746**. First gap **744** is in series with a magnetic flux path **748** in magnetic core **208** magnetically coupling first primary winding **210** and first secondary winding **214**, and second gap **746** is in series with a magnetic flux path **750** magnetically coupling second primary winding **212** and second secondary winding **216**. First gap **744** is filled with a first gap material **752**, and second gap **746** is filled with a second gap material **754**, where each of first gap material **752** and second gap material **754** have a lower magnetic permeability than a magnetic material forming magnetic core **208**. For example, in certain embodiments, first gap material **752** and second gap material **754** each include one or more of air, paper, plastic, glue, and low permeability magnetic material.

[0091] Respective locations of first gap **744** and second gap **746** may vary, although it is generally desirable that the gaps not be located in a portion of magnetic core that is within magnetic flux paths of both first primary winding **210** and second primary winding **212**, to help minimize magnetic coupling of first primary winding **210** and second primary winding **212**. Accordingly, it is generally desirable that gaps in magnetic core **208** not be located in a portion of magnetic core **208** between first winding window **234** and second winding window **236**.

[0092] FIG. **8** illustrates another possible location of gaps in magnetic core **208**. Specifically, FIG. **8** is a top plan view of a magnetic device **800**, where magnetic device **800** is an embodiment of magnetic device **200** (FIGS. **2-6**) where magnetic core **208** forms a first gap **844** and a second gap **846**. First gap **844** is in series with a magnetic flux path **848** in magnetic core **208** magnetically coupling first primary winding **210** and first secondary winding **214**, and second gap **846** is in series with a magnetic flux path **850** magnetically coupling second primary winding **212** and second secondary winding **216**. First gap **844** is filled with a first gap material **852** analogous to first gap material **752** of FIG. **7**, and second gap **846** is filled with a second gap material **854** analogous to second gap material **754** of FIG. **7**.

[0093] Returning to FIGS. **2-6**, magnetic core **208** could alternately be formed of magnetic material having a distributed gap instead of being formed of ferrite material or other high permeability magnetic material. For example, magnetic core **208** could be formed of material including powered iron and a binder instead of being formed of a ferrite material. In certain of these embodiments where magnetic core **208** is formed of a magnetic material having a distributed gap, magnetic core **208** does not necessarily form explicit gaps.

[0094] FIGS. **9-11** illustrate an electrical assembly **900**, where electrical assembly **900** is one embodiment of an electrical assembly **100** (FIG. **1**) where magnetic device **106** is embodied by magnetic device **200** (FIGS. **2-6**). FIG. **9** is a front elevational view of electrical assembly **900**, FIG. **10** is a side elevational view of electrical assembly **900**, and FIG. **11** is a top plan view of electrical assembly **900**. FIGS. **9-11** include the same coordinate axes as FIGS. **2-6**. Electrical assembly **900** includes a first substrate **902**, a second substrate **904**, an instance of magnetic device **200**, a first switching stage **906**, a second switching stage **908**, and a plurality of capacitors **910**, only one of which is labeled in FIGS. **9** and **10**. Electrical assembly **900** may include additional elements, such as discussed below with respect to FIG. **12**, without departing from the scope hereof. First substrate **902** is an embodiment of first substrate **102** (FIG. **1**), and second substrate **904** is an embodiment of second substrate **104** (FIG. **1**). First substrate **902** and second substrate **904** are separated from each other in first direction **202**, and magnetic device **200** is disposed between first substrate **902** and second substrate **904** in first direction **202**. End **218** of first primary winding **210**, end **222** of second primary winding **212**, ends **226** and **228** of first secondary winding **214**, and ends **230** and **232** of second secondary winding **216** are connected to a bottom surface **912** of first substrate **902** by surface mount soldering. End **220** of first primary winding **210** and end **224** of second primary winding **212** are connected to a top surface **914** of second substrate **904** by surface mount soldering. In some alternate embodiments, the winding ends are connected to first substrate **902** and/or second substrate **904** by a method other than surface mount soldering, such as by through-hole pins soldered into plated through-holes in the substrates.

[0095] FIG. **11** illustrates in dashed lines outlines of winding ends that are connected to bottom surface **912** of first substrate **902**, where bottom surface **912** is opposite of a top surface **914** of first substrate. Each of first switching stage **906** and second switching stage **908** is on first substrate **902**. First switching stage **906** is electrically coupled **920** to end **218** of first primary winding **210**, and second switching stage **908** is electrically coupled **922** to end **222** of second primary winding **212**. An electrical conductor **924** of first substrate **902** electrically couples end **228** of first secondary winding **214** to end **230** of second secondary winding **216**, thereby coupling first secondary winding **214** and second secondary winding **216** in series. Electrical conductor **924** includes, for example, a PCB trace or a PCB conductive polygon. Capacitors **910** are located on a bottom surface **918** of second substrate **904**. In certain embodiments, capacitors **910** are electrically coupled to each of end **220** of first primary winding **210** and end **224** of second primary winding **212**.

[0096] In particular embodiments, magnetic device **200**, first switching stage **906**, second switching stage **908**, and capacitors **910** form part of a multi-phase switching power converter. For example, FIG. **12** is an electrical schematic diagram of a multi-phase switching power converter **1200** at least partially formed by elements of electrical assembly **900**. It is understood, though, that electrical assembly **900** is not limited to forming the FIG. **12** multi-phase switching power converter. Multi-phase switching power converter **1200** includes an instance of magnetic device **200**, first switching stage **906**, second switching stage **908**, output capacitance **1202**, a tuning inductor **1204**, and a controller **1206**. Tuning inductor **1204** and controller **1206**, which are not shown in FIGS. **9-11**, are illustrated in FIG. **12** as being on first substrate **204**. However, tuning inductor **1204** and/or controller **1206** could be located elsewhere without departing from the scope hereof. For example, tuning inductor **1204** and/or controller **1206** could be located on second substrate **904** instead of on first substrate **902**. As another example, tuning inductor **1204** and/or controller **1206** could be located external to both of first substrate **902** and second substrate **904**.

[0097] First switching stage **906**, first primary winding **210**, and first secondary winding **214** collectively form a first phase **1208** of multi-phase switching power converter **1200**, and second switching stage **908**, second primary winding **212**, and second secondary winding **216** collectively form a second phase **1210** of multi-phase switching power converter **1200**. First primary winding **210** is electrically coupled between a first switching node X(**1**) and an output power node **1212**, and second primary winding **212** is electrically coupled between a second switching node X(**2**) and output power node **1212**. Output power node **1212** has a voltage V.sub.out relative to a ground node **1214**, and an output current I.sub.out flows to a load (not shown) electrically coupled to output power node **1212**. Output current I.sub.out could have a negative polarity without departing from the scope hereof. Output capacitance **1202**, which represents collective capacitance of all capacitors **910** of electrical assembly **900**, is electrically coupled between output power node **1212** and ground node **1214**. Ground node **1214** need not be an earth ground node, and ground node **1214** accordingly could be at a different electrical potential than an earth ground. For example, ground node **1214** could be reference node that is floating with respect to an earth ground.

[0098] First switching stage **906** is configured to repeatedly switch first switching node X(**1**) between an input power node **1216** and ground node **1214** in response to control signals U(**1**) and L(**1**) generated by controller **1206**, and second switching stage **908** is configured to repeatedly switch second switching node X(**2**) between input power node **1216** and ground node **1214** in response to control signals U(**2**) and L(**2**) generated by controller **1206**. Connections between controller **1206** and first switching stage **906** and second switching stage **908** are not shown for illustrative clarity, although it is understood that one or more communication buses may communicatively couple control signals U and L from controller **1206** to first switching stage **906** and second switching stage **908**. Input power node **1216** is at a voltage V.sub.in relative to ground node **1214**. Accordingly, first switching stage **906** repeatedly switches first switching node X(**1**) between voltage V.sub.in and zero volts relative to ground node **1214**, and second switching stage **908** repeatedly switches second switching node X(**2**) between voltage V.sub.in and zero volts relative to ground node **1214**. An input current I.sub.in flows from an electrical power source (not shown) to multi-phase switching power converter **1200** via input power node **1216**. Input current I.sub.in could have a negative polarity without departing from the scope hereof. One or more input capacitors (not shown) are optionally electrically coupled between input power node **1216** and ground node **1214**.

[0099] First switching stage **906** includes an upper switching device **1218** and a lower switching device **1220**. Upper switching device **1218** is electrically coupled between input power node **1216** and first switching node X(**1**), and lower switching device **1220** is electrically coupled between first switching node X(**1**) and ground node **1214**. Second switching stage **908** includes an upper switching device **1222** and a lower switching device **1224**. Upper switching device **1222** is electrically coupled between input power node **1216** and second switching node X(**2**), and lower switching device **1224** is electrically coupled between second switching node X(**2**) and ground node **1214**. Upper switching devices **1218** and **1222** switch in response to a respective control signals U(**1**) and U(**2**) from controller **1206**, and lower switching devices **1220** and **1224** switch in response to a respective control signals L(**1**) and L(**2**) from controller **1206**. Each of upper switching device **1218**, lower switching device **1220**, upper switching device **1222**, and lower switching device **1224** includes, for example, one or more transistors.

[0100] First secondary winding **214**, second secondary winding **216**, and tuning inductor **1204** are electrically coupled in series. While FIG. **12** illustrates the series connection including first secondary winding **214**, second secondary winding **216**, and tuning inductor **1204** being reference to ground node **1214**, in some alternate embodiments, these elements are electrically coupled in series without being referenced to ground node **1214**. Tuning inductor **1204** could be omitted without departing from the scope hereof, such as in embodiments where there is significant stray inductance in magnetic device **200**.

[0101] Controller **1206** is implemented, for example, by analog and/or electronic circuitry. In some embodiments, controller **1206** is at least partially implemented by a processor (not shown) executing instructions in the form of software and/or firmware stored in a memory (not shown). Although controller **1206** is depicted as a discrete element for illustrative simplicity, controller **1206** could be partially or fully integrated with one or more other elements of multi-phase switching power converter **1200**. For example, some subsystems of controller **1206** could be incorporated in one or more of first switching stage **906** and second switching stage **908**. Additionally, FIG. **12** should not be construed to require that there be a separate communication bus for each control signal. For example, controller **1206** could be implemented by a combination of a central integrated circuit and local control logic integrated in each of first switching stage **906** and second switching stage **908**, with a single communication bus running from the central integrated circuit to each of first switching stage **906** and second switching stage **908**. Furthermore, controller **1206** may include multiple constituent elements that need not be co-packaged or even disposed at a common location

[0102] Controller **1206** is configured to generate control signals U and L to control duty cycle (D) of each of first phase **1208** and **2120**, where duty cycle of phase **1208** or **1210** is a portion of a switching cycle of the phase that the respective primary winding **210** or **212** of the phase is driven high, i.e., when the switching node X(**1**) or X(**2**) of the phase is connected to input power node **1216**, to regulate at least one parameter of multi-phase switching power converter **1200**. In some embodiments, controller **1206** is configured to control duty cycle of first phase **1208** and second phase **1210** using pulse width modulation (PWM) and/or pulse frequency modulation (PFM). Examples of possible regulated parameters include, but are not limited, magnitude of input voltage V.sub.in, magnitude of input current I.sub.in, magnitude of output voltage V.sub.out, and magnitude of output current I.sub.out. For example, in some embodiments, controller **1206** is configured to generate control signals U and L to regulate magnitude of output voltage V.sub.out, and controller **1206** accordingly generates control signals U and L during continuous conduction operation of multi-phase switching power converter **1200** such that duty cycle of each of first phase **1208** and second phase **1210** is equal to a ratio of output voltage magnitude V.sub.out over input voltage magnitude V.sub.in. For example, if output voltage V.sub.out is to be regulated to two volts and input voltage V.sub.in is eight volts, controller **1206** would generate control signals U and L such that duty cycle of each of first phase **1208** and second phase **1210** is 0.25. Controller **1206** is optionally configured to generate control signals U and L such that first phase **1208** and second phase **1210** switch out-of-phase with each other.

[0103] It should be appreciated that first phase **1208** and second phase **1210** are electrically coupled by the series connection of first secondary winding **214** and second secondary winding **216** via electrical conductor **924** of first substrate **902** (FIG. **11**). The electrical coupling of first phase **1208** and second phase **1210** advantageously promotes fast transient response and/or low ripple current magnitude relative to an otherwise similar multi-phase switching power converter without electrical coupling of phases.

[0104] Multi-phase switching power converter **1200** could be modified to include additional phases by adding a respective switching stage for each additional phase, as well as by modifying magnetic device **200** to include an additional primary winding and an additional secondary winding for each additional phase. One example of an alternate embodiment of magnetic device **200** including additional primary and second winding pairs is discussed below with respect to FIGS. **32-36**. Additionally, while each of first phase **1208** and second phase **1210** powers common output power node **1212** in multi-phase switching power converter **1200**, multi-phase switching power converter

1200 could be modified so that two or more phases power different output power nodes. Furthermore, although each of first phase **1208** and second phase **1210** is powered by a common input power node **1216** in multi-phase switching power converter **1200**, multi-phase switching power converter **1200** could be modified so that two or more phases are powered by different respective input power nodes. Moreover, while multi-phase switching power converter **1200** has a buck topology, multi-phase switching power converter **1200** could be modified to have a different topology, e.g., a boost topology or a buck-boost topology. Additionally, while a single tuning inductor **1204** electrically couples two phases of multi-phase switching power converter **1200** in FIG. **12**, tuning inductor **1204** could similarly couple more phases. For example, tuning inductor **1204** could be electrically coupled in series with each secondary winding in a four-phase switching power converter incorporating a magnetic device with four winding sets, such as a magnetic device **3200** discussed below with respect FIG. **32**. Furthermore, a single tuning inductor **1204** could be electrically coupled is series with secondary windings of several magnetic devices having different respective quantities of winding sets. For example, a single instance of tuning inductor **1204** could be electrically coupled in series with each of (i) secondary windings of one instance of magnetic device **3200** of FIG. **32**, (ii) the respective secondary windings of two instances of magnetic device **200**, (iii) the respective secondary windings of three instances of a magnetic device with a single winding set, such as magnetic device **3700** discussed below with respect to FIG. **37**.

[0105] FIGS. **13-15** illustrate an electrical assembly **1300**, which is an alternate embodiment of electrical assembly **900** (FIGS. **9-11**) where (i) each of first switching stage **906** and second switching stage **908** are located on second substrate **904** instead of on first substrate **902** and (ii) capacitors **910** are located first substrate **902** instead of on second substrate **904**. FIG. **13** is a front elevational view of electrical assembly **1300**, FIG. **14** is a side elevational view of electrical assembly **1300**, and FIG. **15** is a top plan view of electrical assembly **1300**. Only one instance of a capacitor **910** is labeled in each FIGS. **13-15**. Electrical assembly **1300** optionally forms at least part of a multi-phase switching power converter similar to multi-phase switching power converter **1200** of FIG. **12**, but with opposing ends of each winding swapped. For example, end **218** of first primary winding **210** is connected to output power node **1212** instead of to first switching node X(**1**), and end **220** of first primary winding **210** is electrically coupled to first switching node X(**1**) instead of to output power node **1212**, in embodiments of electrical assembly **1300** forming a multi-phase switching power converter similar to multi-phase switching power converter **1200**.

[0106] Referring again to FIG. **2**, it is anticipated first secondary winding **214** and second secondary winding **216** will frequently conduct zero, or essentially zero, direct current (DC) in multi-phase switching power converter applications of magnetic device **200**. Consequently, in particular embodiments, first secondary winding **214** and second secondary winding **216** need not be capable of carrying as much current as first primary winding **210** and second primary winding **212**. While it may be desirable for all windings of magnetic device **200** to have a common thickness to promote planarity, in some applications, first secondary winding **214** and second secondary winding **216** may be modified to have smaller widths than first primary winding **210** and second primary winding **212** due to the secondary windings carrying current of smaller magnitude than the primary windings.

[0107] For example, FIGS. **16-19** collectively illustrate a magnetic device **1600**, which is an alternate embodiment of magnetic device **200** (FIGS. **2-6**) having a different secondary winding configuration, as well as a different winding window configuration. FIG. **16** is a top plan view of magnetic device **1600**, FIG. **17** is a front elevational view of magnetic device **1600**, FIG. **18** is a side elevational view of magnetic device **1600**, and FIG. **19** is a bottom plan view of magnetic device **1600**. Magnetic device **1600** differs from magnetic device **200** in that (i) magnetic core **208** is replaced with a magnetic core **1608**, (ii) first secondary winding **214** is replaced with a first secondary winding **1614**, and (iii) second secondary winding **216** is replaced with a second secondary winding **1616**. Magnetic core **1608** differs from magnetic core **208** in its dimensions and that first winding window **234** and second winding window **236** are replaced with a first winding window **1634** and a second winding window **1636**, respectively. First winding window **1634** and second winding window **1636** are longer in second direction **204** than corresponding winding windows in magnetic core **208**, but first winding window **1634** and second winding window **1636** are narrower in third direction **206** than corresponding winding windows in magnetic core **208**. Consequently, magnetic core **1608** is longer is second direction **204**, but narrower in third direction **206**, than magnetic core **208**.

[0108] First secondary winding **1614** and second secondary winding **1616** are narrower than first secondary winding **214** and second secondary winding **216**, respectively. First secondary winding **1614** has opposing ends **1626** and **1628** in place of opposing ends **226** and **228**, respectively. Additionally, second secondary winding **1616** has opposing ends **1630** and **1632** in place of opposing ends **230** and **232**, respectively. First primary winding **210** is separated from first secondary winding **1614** in first winding window **1634** in second direction **204**, and second primary winding **212** is separated from second secondary winding **1616** in second winding window **1636** in second direction **204**.

[0109] Referring again to FIG. **1**, stray inductance between the primary winding **114** and the secondary winding **116** in a given winding set **112** can be helpful in some applications. For example, if such inductance is sufficiently large, it may eliminate the need for a tuning inductor, e.g., tuning inductor **1204** of FIG. **12**, in embodiments where electrical assembly **100** forms part of a multi-phase switching power converter. However, excessive inductance between the primary winding **114** and the secondary winding **116** in a given winding set **112** may be detrimental because it impairs transient response of a multi-phase switching power converter including electrical assembly **100**. Stray inductance between the primary winding **114** and the secondary winding **116** in a given winding set **112** can be reduced by reducing size of a current loop incorporating the primary winding **114** and the secondary winding **116** of a given winding set **112**. Accordingly, any of the magnetic devices disclosed herein may include a respective ground conductor near each secondary winding, to help cause ground current flowing between opposing substrates to flow near the secondary windings, thereby helping reduce stray inductance between the primary winding **114** and the secondary winding **116** of each winding set **112**. The ground conductors electrically couple a ground node of first substrate **102** to a ground node of second substrate **104**.

[0110] For example, FIGS. **20-24** illustrate a magnetic device **2000**, where magnetic device **2000** is an alternate embodiment of magnetic device **1600** (FIGS. **16-19**) further including a respective ground conductor for each secondary winding. FIG. **20** is a top plan view of magnetic device **2000**, FIG. **21** is a front elevational view of magnetic device **2000**, FIG. **22** is a side elevational view of magnetic device **2000**, FIG. **23** is a bottom elevational view of magnetic device **2000**, and FIG. **24** is a cross-sectional view of magnetic device **2000** taken along line **24**A-**24**A of FIG. **20**. Magnetic device **2000** differs from magnetic device **1600** in that magnetic device **2000** further includes (i) a first ground conductor **2002** disposed adjacent to first secondary winding **1614** and (ii) a second ground conductor **2004** disposed adjacent to second secondary winding **1616**. Each of first ground conductor **2002** and second ground conductor **2004** extend along a side outer surface **1642** of magnetic core **1608**, and each of first ground conductor **2002** and second ground conductor **2004** wraps around magnetic core **1608** to extend over each of a top outer surface **1638** of magnetic core **1608** and a bottom outer surface **1640** of magnetic core **1608**. Neither first ground conductor **2002** nor second ground conductor **2004**, however, forms a complete loop around any portion of magnetic core **1608**, to help minimize inductance associated with first ground conductor **2002** and second ground conductor **2004**.

[0111] FIG. **25** is a front elevational view of an electrical assembly **2500**, which is an alternate embodiment of electrical assembly **900** (FIGS. **9-11**) with magnetic device **200** replaced with magnetic device **2000**. Opposing ends of each of first ground conductor **2002** and second ground conductor **2004** are surface mount soldered to first substrate **902** and second substrate **904**,

respectively, although first ground conductor **2002** and second ground conductor **2004** could be connected to first substrate **902** and/or second substrate **904** in an alternative manner, e.g., by through-hole pins. Each of first ground conductor **2002** and second ground conductor **2004** electrically couple a ground node of first substrate **902** and a ground node of second substrate **904**. For example, FIG. **26** is an electrical schematic diagram of a multi-phase switching power converter **2600** at least partially formed by elements of the FIG. **25** electrical assembly. Multi-phase switching power converter **2600** is the same as multi-phase switching power converter **1200** of FIG. **12** except that multi-phase switching power converter **2600** includes magnetic device **2000** in place of magnetic device **200**. First ground conductor **2002** and second ground conductor **2004** electrically couple respective ground nodes **1214** of each of first substrate **902** and second substrate **904**, as shown in FIG. **26**. Additionally, FIG. **26** illustrates (i) magnetic coupling **2006** of first secondary winding **214** and first ground conductor **2002** and (ii) magnetic coupling **2008** of second secondary winding **216** and second ground conductor **2004**.
[0112] The magnetic devices disclosed herein could also include a respective ground conductor wound around each secondary winding, to help minimize separation between the ground conductors and the secondary windings. For example, FIGS. **27-31** illustrate a magnetic device **2700**, which is an alternate embodiment of magnetic device **1600** (FIGS. **16-19**) including a respective ground conductor wound around each secondary winding. FIG. **27** is top plan view of magnetic device **2700**, FIG. **28** is a front elevational view of magnetic device **2700**, FIG. **29** is a side elevational view of magnetic device **2700**, FIG. **30** is a cross-sectional view of magnetic device **2700** taken along line **30**A-**30**A of FIG. **27**, and FIG. **31** is a bottom plan view of magnetic device **2700**. Magnetic device **2700** differs from magnetic device **1600** in that (i) first secondary winding **1614** and second secondary winding **1616** are replaced with a first secondary winding **2714** and a second secondary winding **2716**, respectively, (ii) magnetic device **2700** further includes a first insulating layer **2706** and a second insulating layer **2708**, and (iii) magnetic device **2700** further includes a first ground conductor **2702** and a second ground conductor **2704**.
[0113] First secondary winding **2714** is wound through first winding window **1634**, along bottom outer surface **1640** of magnetic core **1608**, and along side outer surface **1642** of magnetic core **1608** such that an end **2726** and an end **2728** of first secondary winding **2714** are each on top outer surface **1638** of magnetic core **1608**. Additionally, second secondary winding **2716** is wound through second winding window **1636**, along bottom outer surface **1640** of magnetic core **1608**, and along side outer surface **1642** of magnetic core **1608** such that an end **2730** and an end **2732** of second secondary winding **2716** are each on top outer surface **1638** of magnetic core **1608**. First secondary winding **2714** is separated from first primary winding **210** in third direction **206** within winding window **1634**, and second secondary winding **2716** is separated from second primary winding **212** in third direction **206** within winding window **1636**.
[0114] First insulating layer **2706** is wrapped over first secondary winding **2714**, and first ground conductor **2702** is wrapped over first insulating layer **2706**. Additionally, second insulating layer **2708** is wrapped over second secondary winding **2716**, and second ground conductor **2704** is wrapped over second insulating layer **2708**. As such, first ground conductor **2702** is wound around first secondary winding **2714**, but first ground conductor **2702** is separated from first secondary winding **2714** by first insulating layer **2706** to prevent electrical shorting of first secondary winding **2714** and first ground conductor **2702**. Additionally, second ground conductor **2704** is wound around second secondary winding **2716**, but second ground conductor **2704** is separated from second secondary winding **2716** by second insulating layer **2708** to prevent electrical shorting of second secondary winding **2716** and second ground conductor **2704**. Accordingly, each of first ground conductor **2702** and second ground conductor **2704** extend along side outer surface **1642** of magnetic core **1608**, and each of first ground conductor **2702** and second ground conductor **2704** wraps around magnetic core **1608** to extend over each of top outer surface **1638** of magnetic core **1608** and bottom outer surface **1640** of magnetic core **1608**. Neither first ground conductor **2702**

nor second ground conductor **2704**, however, forms a complete loop around any portion of magnetic core **1608**, to help minimize inductance associated with first ground conductor **2702** and second ground conductor **2704**.

[0115] The magnetic devices discussed above with respect to FIGS. **2-31** include two winding sets, where each winding set includes a respective primary winding and a respective secondary winding. However, any of the above-discussed magnetic devices could be modified to include one or more additional winding sets, such as to support additional phases in a multi-phase switching power converter. For example, magnetic device **200** of FIGS. **2-6** could be extended in second direction **204** and/or in third direction **206** to include one or more winding windows and an associated winding set for each additional window. For instance, FIGS. **32-36** illustrate a magnetic device **3200**, which is an alternate embodiment of magnetic device **200** extended in third direction **206** to include additional winding windows and associated winding sets. FIG. **32** is a top plan view of magnetic device **3200**, FIG. **33** is a front elevational view of magnetic device **3200**, FIG. **34** is a side elevational view of magnetic device **3200**, FIG. **35** is a bottom plan view of magnetic device **3200**, and FIG. **36** is a cross-sectional view of magnetic device **3200** taken along line **36**A-**36**A of FIG. **32**.

[0116] Magnetic device **3200** differs from magnetic device **200** in that (i) magnetic device **3200** includes a magnetic core **3208** in place of magnetic core **208**, (ii) magnetic device **3200** further includes a third primary winding **3244** and a fourth primary winding **3246**, and (ii) magnetic device **3200** further includes a third secondary winding **3248** and a fourth secondary winding **3250**. Magnetic core **3208** differs from magnetic core **208** in that magnetic core **3208** is wider in third direction **206** and magnetic core **3208** forms two additional winding windows, i.e., a third winding window **3252** and a fourth winding window **3254**. Each of third winding window **3252** and fourth winding window **3254** extends through magnetic core **3208** in first direction **202**. Magnetic core **3208** includes a top outer surface **3238**, a bottom outer surface **3240**, and a front outer surface **3242** in place of top outer surface **238**, bottom outer surface **240**, and front outer surface **242**, respectively. Each of third primary winding **3244** and fourth primary winding **3246** is an embodiment of a primary winding **114** of FIG. **1**, and each of third secondary winding **3248** and fourth secondary winding **3250** is an embodiment of a secondary winding **116** of FIG. **1**. Third primary winding **3244** has opposing ends **3256** and **3258**, and fourth primary winding **3246** has opposing ends **3260** and **3262**. Third secondary winding **3248** has opposing ends **3264** and **3266**, and fourth secondary winding **3250** has opposing ends **3268** and **3270**.

[0117] Third primary winding **3244** is wound through third winding window **3252** and around a portion of magnetic core **3208** such that (i) end **3256** of third primary winding **3244** is on top outer surface **3238** of magnetic core **3208** and (ii) end **3258** of third primary winding **3244** is on bottom outer surface **3240** of magnetic core **3208**. Similarly, fourth primary winding **3246** is wound through fourth winding window **3254** and around a portion of magnetic core **3208** that (i) end **3260** of fourth primary winding **3246** is on top outer surface **3238** of magnetic core **3208** and (ii) end **3262** of fourth primary winding **3246** is on bottom outer surface **3240** of magnetic core **3208**. Third secondary winding **3248** is wound through third winding window **3252**, along bottom outer surface **3240** of magnetic core **3208**, and along a back outer surface **3272** of magnetic core **3208** such that end **3264** and end **3266** of third secondary winding **3248** are each on top outer surface **3238** of magnetic core **3208**. Additionally, fourth secondary winding **3250** is wound through fourth winding window **3254**, along bottom outer surface **3240** of magnetic core **3208**, and along back outer surface **3272** of magnetic core **3208** such that end **3268** and end **3270** of fourth secondary winding **3250** are each on top outer surface **3238** of magnetic core **3208**.

[0118] Any of the above-discussed magnetic devices could also be modified to include only a single winding set. For example, FIGS. **37-40** illustrate a magnetic device **3700**, which is an alternate embodiment of magnetic device **200** (FIGS. **2-6**) modified to include only a single winding set. FIG. **37** is a top plan view of magnetic device **3700**, FIG. **38** is a front elevational view of magnetic device **3700**, FIG. **39** is a side elevational view of magnetic device **3700**, and FIG. **40** is a bottom plan view of magnetic device **3700**. Magnetic device **3700** differs from magnetic device **200** in that (i) magnetic core **208** is replaced with a magnetic core **3708**, (ii) second primary winding **212** is omitted, and (iii) secondary winding **216** is omitted. Magnetic core **3708** includes a top outer surface **3738**, a bottom outer surface **3740**, and front outer surface **3742** in place of top outer surface **238**, bottom outer surface **240**, and front outer surface **242**, respectively. First primary winding **210** is henceforth referred to as "primary winding **210**" instead of "first primary winding **210**" in the context of magnetic device **3700** because magnetic device **3700** includes only one primary winding. Similarly, first secondary winding **214** is henceforth referred to as "secondary winding **214**" instead of "first secondary winding **214**" in the context of magnetic device **3700** because magnetic device **3700** includes only one secondary winding.

[0119] An electrical assembly may include multiple instances of magnetic device **3700** to support multiple phases, such as a respective instance of magnetic device **3700** for each phase of a multi-phase switching power converter. For example, FIGS. **41** and **42** illustrate an electrical assembly **4100**, where electrical assembly **4100** is an alternate embodiment of electrical assembly **900** (FIGS. **9-11**) including two instances of magnetic device **3700** in place of magnetic device **200** (FIGS. **2-6**). FIG. **41** is a front elevational view of electrical assembly **4100**, and FIG. **42** is a top plan view of electrical assembly **4100**. Only one instance of capacitors **910** is labeled in FIG. **41**. Electrical assembly **4100** differs from electrical assembly **900** in that (i) magnetic device **200** is replaced with two instance of magnetic device **3700**, i.e., magnetic devices **3700(1)** and **3700(2)**, (ii) first substrate **902** is replaced with a first substrate **4102**, and (iii) second substrate **904** is replaced with a second substrate **4104**. First substrate **4102** is similar to, but larger than, first substrate **902**, and second substrate **4104** is similar to, but larger than, second substrate **904**. First substrate **4102** includes a bottom surface **4112** and top surface **4116**, and second substrate **4104** includes a bottom surface **4118** and a top surface **4114**.

[0120] First substrate **4102** and second substrate **4104** are separated from each other in first direction **202**, and each magnetic device **3700** is disposed between first substrate **4102** and second substrate **4104** in first direction **202**. Magnetic devices **3700** are separated from each other in second direction **204**, and in some alternate embodiments, magnetic devices **3700** are separated from each other in third direction **206**, in place of, or in addition to, being separated from each other in second direction **204**. Ends **218** of primary windings **210**, ends **226** of secondary windings **214**, and ends **228** of secondary windings **214** are connected to bottom surface **4112** of first substrate **4102** by surface mount soldering. Ends **220** of primary windings **210** are connected to top surface **4114** of second substrate **4104**. In some alternate embodiments, the winding ends are connected to first substrate **4102** and/or second substrate **4104** by a method other than surface mount soldering, such as by through-hole pins soldered into plated through-holes in the substrates.

[0121] FIG. **42** illustrates in dashed lines outlines of winding ends that connect to bottom surface **4112** of first substrate **4102**. Each of first switching stage **906** and second switching stage **908** is on first substrate **4102**. First switching stage **906** is electrically coupled **4120** to end **218(1)** of primary winding **210(1)** of magnetic device **3700(1)**, and second switching stage **908** is electrically coupled **4122** to end **218(2)** of primary winding **210(2)** of magnetic device **3700(2)**. An electrical conductor **4124** of first substrate **4102** electrically couples end **228(1)** of secondary winding **214(1)** of magnetic device **3700(1)** to end **226(2)** of secondary winding **214(2)** of magnetic device **3700(2)**, thereby coupling secondary winding **214(1)** and secondary winding **214(2)** in series. Electrical conductor **4124** includes, for example, a PCB trace or a PCB conductive polygon.

[0122] In particular embodiments, magnetic device **3700(1)**, magnetic device **3700(2)**, first switching stage **906**, second switching stage **908**, and capacitors **910** of electrical assembly **4100** form part of a multi-phase switching power converter. For example, in some embodiments, the aforementioned elements of electrical assembly **4100** form a multi-phase switching power converter similar to multi-phase switching power converter **1200** of FIG. **12** where (i) primary winding **210**(**1**) of magnetic device **3700**(**1**) is electrically coupled between switching node X(**1**) and output power node **1212**, (ii) primary winding **210**(**2**) of magnetic device **3700**(**2**) is electrically coupled between switching node X(**2**) and output power node **1212**, and (iii) secondary winding **214**(**1**) of magnetic device **3700**(**1**) and secondary winding **214**(**2**) of magnetic device **3700**(**2**) are electrically coupled in series with tuning inductor **1204**.

[0123] FIGS. **43-45** illustrate an electrical assembly **4300**, which is an alternate embodiment of electrical assembly **4100** (FIGS. **41** and **42**) where second substrate **4104** is replaced with a respective additional substrate **4304** for each magnetic device **3700**, and where each additional substrate **4304** includes a top surface **4314** and a bottom surface **4318**. First substrate **4102** remains as a common substrate for each magnetic device **3700** in electrical assembly **4300**. FIG. **43** is a front elevational view of electrical assembly **4300**, FIG. **44** is a top plan view of electrical assembly **4300**, and FIG. **45** is a bottom plan view of electrical assembly **4300**. Electrical assembly **4300** additionally differs from electrical assembly **4100** in that (i) first switching stage **906** is located on first additional substrate **4304**(**1**) instead of on first substrate **4102**, (ii) second switching stage **908** is located on second additional substrate **4304**(**2**) instead of on first substrate **4102**, and (iii) capacitors **910** are located on substrate **902** instead of on second substrate **4104**. Only one instance of capacitors **910** is labeled in each of FIGS. **43** and **44**. First switching stage **906** is electrically coupled **4320** to end **220**(**1**) of primary winding **210**(**1**) of magnetic device **3700**(**1**) on additional substrate **4304**(**1**), as illustrated in FIG. **45**. Additionally, second switching stage **908** is electrically coupled **4322** to end **220**(**2**) of primary winding **210**(**2**) of magnetic device **3700**(**2**) on additional substrate **4304**(**2**), as also illustrated in FIG. **45**.

[0124] FIG. **46** is an electrical schematic diagram of a multi-phase switching power converter **4600** at least partially formed by elements of electrical assembly **4300** (FIGS. **43-45**). It is understood, though, that electrical assembly **4300** is not limited to forming the FIG. **46** multi-phase switching power converter. Multi-phase switching power converter **4600** is similar to multi-phase switching power converter **1200** of FIG. **12** except that multi-phase switching power **4400** includes two instances of magnetic device **3700**, i.e., magnetic device **3700**(**1**) and **3700**(**2**), in place of magnetic device **200**. Additionally, the arrangement of elements among substrates differs between multi-phase switching power converter **4400** and multi-phase switching power converter **1200**. For example, first switching stage **906** and second switching stage **908** are located on respective additional substrates **4304**(**1**) and **4304**(**1**), instead of on common substrate **902**, in multi-phase switching power converter **4600**. As another example, tuning inductor **1204** (not shown in FIGS. **43-45**) is located on first substrate **4102** in multi-phase switching power converter **4600**.

[0125] The primary winding and the secondary winding of a given winding set form a common number of turns, such that a turns ratio is 1:1, in the example magnetic devices discussed above. However, any of the magnetic device disclosed herein could be modified so that the primary winding and the secondary winding of a given winding set form different respective numbers of turns, to obtain a turns ratio other than 1:1. For example, FIGS. **47-51** illustrate a magnetic device **4700**, which is an alternate embodiment of magnetic device **2000** (FIGS. **20-24**) with primary windings forming two turns each. FIG. **47** is a top plan view of magnetic device **4700**, FIG. **48** is a front elevational view of magnetic device **4700**, FIG. **49** is a side elevational view of magnetic device **4700**, FIG. **50** is a bottom plan view of magnetic device **4700**, and FIG. **51** is a back elevational view of magnetic device **4700**.

[0126] Magnetic device **4700** differs from magnetic device **2000** in that (i) first primary winding **210** is replaced with a first primary winding **4710** and (i) second primary winding **212** is replaced with a second primary winding **4712**. First primary winding **4710** is wound along a back outer surface **4744** of magnetic core **1608** and through first winding window **1634** to form two turns, and first primary winding **4710** has opposing ends **4718** and **4720**. End **4718** is analogous to end **218** of first primary winding **210**, and end **4718** is accordingly on top outer surface **1638** of magnetic core **1608**. End **4720** is analogous to end **220** of first primary winding **210**, and end **4720** is accordingly on bottom outer surface **1640** of magnetic core **1608**. Similarly, second primary winding **4712** is wound along back outer surface **4744** of magnetic core **1608** and through second winding window **1636** to form two turns, and second primary winding **4712** has opposing ends **4722** and **4724**. End **4722** is analogous to end **222** of second primary winding **212**, and end **4722** is accordingly on top outer surface **1638** of magnetic core **1608**. End **4724** is analogous to end **224** of second primary winding **210**, and end **4724** is accordingly on bottom outer surface **1640** of magnetic core **1608**.

[0127] Magnetic device **4700** is scalable in second direction **204**, or stated differently, magnetic device **4700** could be modified by extending magnetic core **1608** in second direction **204** and adding one or more winding windows and associated winding sets that are separated from each other in second direction **204**. However, magnetic device **4700** is not scalable in third direction **206** due to windings being wound around both front outer surface **1642** of magnetic core **1608** and back outer surface **4744** of magnetic core **1608**. FIGS. **52-54** illustrate a magnetic device **5200** which is an alternate embodiment of magnetic device **4700** (FIGS. **47-51**) that is scalable in third direction **206** as well as in second direction **204**. FIG. **52** is a top plan view of magnetic device **5200**, FIG. **53** is a front elevational view of magnetic device **5200**, and FIG. **54** is a bottom plan view of magnetic device **5200**.

[0128] Magnetic device **5200** differs from magnetic device **4700** in that (i) magnetic core **1608** is replaced with a magnetic core **5208**, (ii) first primary winding **4710** and second primary winding **4712** are replaced with a first primary winding **5210** and a second primary winding **5212**, respectively, (iii) magnetic device **5200** further includes a third primary winding **5246** and a fourth primary winding **5248**, (iv) magnetic device **5200** further includes a third secondary winding **5250** and a fourth secondary winding **5252**, and (v) magnetic device **5200** further include a third ground conductor **5254** and a fourth ground conductor **5256**. Magnetic core **5208** includes a top outer surface **5238**, a bottom outer surface **5240**, a front outer surface **5242**, and a back outer surface **5244** in place of top outer surface **1638**, bottom outer surface **1640**, front outer surface **1642**, and back outer surface **4744**, respectively.

[0129] Magnetic core **5208** forms a third winding window **5258** and a fourth winding window **5260** each extending through first magnetic core **5208** in first direction **202**, in addition to first winding window **1634** and second winding window **1636**. Each of first ground conductor **5202** and second ground conductor **5204** extends along front outer surface **5242** of magnetic core **5208**, and each of first ground conductor **5202** and second ground conductor **5204** wraps around magnetic core **5208** to extend over each of top outer surface **5238** of magnetic core **5208** and bottom outer surface **5240** of magnetic core **5208**. Each of third ground conductor **5254** and fourth ground conductor **5256** extends along back outer surface **5244** of magnetic core **5208**, and each of third ground conductor **5254** and fourth ground conductor **5256** wraps around magnetic core **5208** to extend over each of top outer surface **5238** of magnetic core **5208** and bottom outer surface **5240** of magnetic core **5208**.

[0130] First primary winding **5210** is wound along front outer surface **5242** of magnetic core **528** and through first winding window **1634** to form two turns, and first primary winding **5210** has opposing ends **5218** and **5220**. End **5218** is analogous to end **218** of first primary winding **210**, and end **5218** is accordingly on top outer surface **5238** of magnetic core **5208**. End **5220** is analogous to end **220** of first primary winding **210**, and end **5220** is accordingly on bottom outer surface **5240** of magnetic core **5208**. Similarly, second primary winding **5212** is wound along front outer surface **5242** of magnetic core **5208** and through second winding window **1636** to form two turns, and second primary winding **5212** has opposing ends **5222** and **5224**. End **5222** is analogous to end **222** of second primary winding **212**, and end **5222** is accordingly on top outer surface **5238** of magnetic core **5208**. End **5224** is analogous to end **224** of second primary winding **210**, and end **5224** is accordingly on bottom outer surface **5240** of magnetic core **5208**. Third primary winding **5246** has opposing ends **5262** and **5264**. Third primary winding **5246** is analogous to first primary winding **5210**, but (i) third primary winding **5246** is wound through third winding window **5258** instead of through first winding window **1634**, and (ii) third primary winding **5246** is wound along back outer surface **5244** instead of along front outer surface **5242**. Fourth primary winding **5248** has opposing ends **5266** and **5268**. Fourth primary winding **5248** is analogous to second primary winding **5212**, but (i) fourth primary winding **5248** is wound through fourth winding window **5260** instead of through second winding window **1636**, and (ii) fourth primary winding **5248** is wound along back outer surface **5244** instead of along front outer surface **5242**.

[0131] Third secondary winding **5250** has opposing ends **5270** and **5272** on top outer surface **5238** of magnetic core **5208**. Third secondary winding **5250** is analogous to first secondary winding **1614** but (i) third second winding **5250** is wound through third winding window **5258** instead of through first winding window **1634**, and (ii) third secondary winding **5250** is wound along back outer surface **5244** instead of along front outer surface **5242**. Fourth secondary winding **5252** has opposing ends **5272** and **5274** on top outer surface **5238** of magnetic core **5208**. Fourth secondary winding **5252** is analogous to second secondary winding **1616**, but (i) fourth secondary winding **5252** is wound through fourth winding window **5260** instead of through second winding window **1636**, and (ii) fourth secondary winding **5252** is wound along back outer surface **5244** instead of along front outer surface **5242**.

[0132] Winding ends are disposed on magnetic core outer surfaces in the above-discussed examples, such as to promote low profile of the magnetic devices. However, any of the magnetic devices disclosed herein could be modified so that one or more winding ends are offset from an adjacent magnetic core outer surface, such as to provide room for components between the magnetic device and adjacent substrates. For example, FIGS. **55-57** illustrate a magnetic device **5500**, which is an alternate embodiment of magnetic device **200** (FIGS. **2-6**) where winding ends are offset from magnetic core outer surfaces. FIG. **55** is a front elevational view of magnetic device **5500**, FIG. **56** is a side elevational view of magnetic device **5500**, and FIG. **57** is a side elevational view of magnetic device **5500** that is opposite the side elevational view of FIG. **56**.

[0133] Magnetic device **5500** differs from magnetic device **200** in that (i) first primary winding **210** is replaced with a first primary winding **5510**, (ii) second primary winding **212** is replaced with a second primary winding **5512**, (iii) first secondary winding **214** is replaced with a first secondary winding **5514**, and (iv) second secondary winding **216** is replaced with a second secondary winding **5516**. First primary winding **5510** differs from first primary winding **210** in that ends **218** and **220** are offset from magnetic core outer surfaces **238** and **240**, respectively, in first direction **202**. Similarly, second primary winding **5512** differs from second primary winding **212** in that ends **222** and **224** are offset from magnetic core outer surfaces **238** and **240**, respectively, in first direction **202**. First secondary winding **5514** differs from first secondary winding **214** in that ends **226** and **228** are offset from magnetic core outer surface **238** in first direction **202**, and second secondary winding **5516** differs from second secondary winding **216** in that ends **230** and **232** are offset from magnetic core outer surface **238** in first direction **202**.

[0134] FIG. **58** is a front elevational view of an electrical assembly **5800**, which is an alternate embodiment of electrical assembly **900** (FIGS. **9-11**) where magnetic device **200** (FIGS. **2-6**) is replaced with magnetic device **5500** (FIGS. **55-57**). It should be noted that the fact that winding ends are offset from magnetic core outer surfaces leaves space **5802** between magnetic core **208** and first substrate **902**, as well as space **5804** between magnetic core **208** and second substrate **904**, for locating additional components (not shown) of electrical assembly **5800**.

[0135] The secondary windings in the above discussed magnetic devices could be modified so that the secondary winding ends terminate on a magnetic core outer surface other than a top outer surface or a bottom outer surface. For example, FIGS. **59-62** illustrate a magnetic device **5900** which is an alternate embodiment of magnetic device **200** (FIGS. **2-6**) where secondary windings terminate on front outer surface **242** of magnetic core **208** instead of on top outer surface **238** of magnetic core **208**. FIG. **59** is a top plan view of magnetic device **5900**, FIG. **60** is a front elevational view of magnetic device **5900**, FIG. **61** is a bottom plan view of magnetic device **5900**, and FIG. **62** is a side elevational view of magnetic device **5900**. Magnetic device **5900** differs from magnetic device **200** in that first secondary winding **214** and second secondary winding **216** are replaced with a first secondary winding **5914** and a second secondary winding **5916**, respectively. First secondary winding **5914** has opposing ends **5926** and **5928** that are analogous to ends **226** and **228** of first secondary winding **214**, respectively, and second secondary winding **5916** has opposing ends **5930** and **5932** that are analogous to ends **230** and **232** of second secondary winding **216**, respectively. Each of ends **5926**, **5928**, **5930**, and **5932** is on outer surface **242** of magnetic core **208**.

[0136] FIG. **63** is a front elevational view of an electrical assembly **6300**, which is an alternate embodiment of electrical assembly **900** (FIGS. **9-11**) where (i) magnetic device **200** is replaced with magnetic device **5900**, (ii) first substrate **902** is replaced with a first substrate **6302**, and (iii) electrical assembly **6300** further includes a third substrate **6304**. FIG. **64** is a side elevational view of electrical assembly **6300**. Third substrate **6304** is placed over winding ends **5926**, **5928**, **5930**, and **5932** is third direction **206**. FIG. **63** illustrates in dashed lines outlines of winding ends **5926**, **5928**, **5930**, and **5932** that are covered by third substrate **6304** in the FIG. **63** elevational view. First substrate **6302** is similar to first substrate **902** of electrical assembly **900**, but first substrate **6302** does not electrically couple secondary windings in series. Instead, third substrate **6304** includes an electrical conductor **6306** electrically coupling end **5928** of first secondary winding **5914** to end **5930** of second secondary winding **5916**, such that first secondary winding **5914** and second secondary winding **5916** are electrically coupled in series. Third substrate **6304** optionally also includes one or more additional electrical conductors (not shown), such as to route one or more signals between first substrate **6302** and second substrate **904**.

[0137] Additionally, the magnetic devices discussed above could be modified so that primary winding ends terminate on a common outer surface of a magnetic core. For example, FIGS. **65-70** illustrate a magnetic device **6500** where primary windings terminate on one magnetic core outer surface and secondary windings terminate on an opposing magnetic core outer surface. FIG. **65** is a top plan view of a magnetic device **6500**, FIG. **66** is a front elevational view of magnetic device **6500**, FIG. **67** is a bottom plan view of magnetic device **6500**, FIG. **68** is a side elevational view of magnetic device **6500**, FIG. **69** is a side elevational view of magnetic **6500** of opposite of the side elevational view of magnetic device **6500** of FIG. **68**, and FIG. **70** is a cross-sectional view of magnetic device **6500** taken along line **70**A-**70**A of FIG. **65**. Magnetic device **6500** includes a magnetic core **6508**, a first primary winding **6510**, a second primary winding **6512**, a first secondary winding **6514**, and second secondary winding **6516**. First primary winding **6510** is magnetically coupled with first secondary winding **6514**, and second primary winding **6512** is magnetically coupled with second secondary winding **6516**. First primary winding **6510** is ideally not magnetically coupled with second primary winding **6512**, but there will typically be some magnetic coupling of first primary winding **6510** and second primary winding **6512** due to the two windings sharing common magnetic core **6508**.

[0138] It is understood that the quantity of windings in magnetic device **6500** may vary, though, as long as magnetic device **6500** includes at least one primary winding and associated secondary winding. For example, magnetic device **6500** could be modified by omitting second primary winding **6512** and second secondary winding **6516**. As another example, magnetic device **6500** could be modified to include one or more winding sets, where each winding set includes a respective primary winding and a respective secondary winding that are magnetically coupled with each other.

[0139] First primary winding **6510** has opposing ends **6518** and **6520**. First primary winding **6510** extends through magnetic core **6508** in second direction **204**. First primary winding **6510** wraps around a side outer surface **6544** of magnetic core **6508** and onto a bottom outer surface **6540** of magnetic core **6508** such that end **6518** is bottom outer surface **6540**. Additionally, first primary winding **6510** wraps around a side outer surface **6546** of magnetic core **6508**, where side outer surface **6546** is opposite of side outer surface **6544**, and onto bottom outer surface **6540** of magnetic core **6508** such that end **6520** is on bottom outer surface **6540**. Second primary winding has opposing ends **6522** and **6524**. Second primary winding **6512** is configured similarly to first primary winding **6510**, but second primary winding **6512** is displaced from first primary winding **6510** in third direction **206**. Accordingly, each of end **6522** and end **6524** of second primary winding **6512** is on second outer surface **6540** of magnetic core **6508**.

[0140] First secondary winding **6514** has opposing ends **6526** and **6528**. First secondary winding **6514** extends through magnetic core **6508** in second direction **204**. First secondary winding **6514** wraps around side outer surface **6544** of magnetic core **6508** and onto a top outer surface **6538** of magnetic core **6508** such that end **6526** is on top outer surface **6538**. Additionally, first secondary winding **6514** wraps around side outer surface **6546** of magnetic core **6508** and onto top outer surface **6538** of magnetic core **6508** such that end **6528** is on top outer surface **6538**. Second secondary winding **6516** has opposing ends **6530** and **6532**. Second secondary winding **6516** is configured similarly to first secondary winding **6514**, but second secondary winding **6516** is displaced from first secondary winding **6514** in third direction **206**. Accordingly, each of end **6530** and end **6532** of second secondary winding **6516** is on top outer surface **6538** of magnetic core **6508**. First secondary winding **6514** is disposed over first primary winding **6510** is first direction **202**, and second secondary winding **6516** is disposed over second primary winding **6512** in first direction **202**. Although FIGS. **65-70** illustrate magnetic device **6500** as being a monolithic element, magnetic device **6500** could be formed by joining two or more elements. For example, in some embodiment, magnetic device **6500** is formed by stacking two elements in first direction **202**, where each element includes a magnetic core and two windings.

[0141] FIGS. **71-73** illustrate an electrical assembly **7100**, where electrical assembly **7100** is one embodiment of an electrical assembly including an instance of magnetic device **6500** (FIGS. **65-70**). FIG. **71** is a front elevational view of electrical assembly **7100**, FIG. **72** is a side elevational view of electrical assembly **7100**, and FIG. **73** is a top plan view of electrical assembly **7100**. Electrical assembly **7100** includes a first substrate **7102**, a second substrate **7104**, an instance of magnetic device **6500**, an instance of first switching stage **906** (discussed above with respect to FIGS. **9-12**), an instance of second switching stage **908** (discussed above with respect to FIGS. **9-12**, a plurality of capacitors **910**, a first pin **7106**, and a second pin **7108**. Only one capacitor **910** instance is labeled in FIGS. **71** and **72**. Electrical assembly **7100** may include additional elements, such as discussed below with respect to FIG. **74**, without departing from the scope hereof.

[0142] First substrate **7102** and second substrate **7104** are separated from each other in first direction **202**, and magnetic device **6500** is disposed between first substrate **7102** and second substrate **7104** in first direction **202**. In some embodiments, each of first substrate **7102** and second substrate **7104** is a respective PCB. End **6518** of first primary winding **6510**, end **6520** of first primary winding **6510**, end **6522** of second primary winding **6512**, and end **6524** of second primary winding **6512** are connected to a top surface **7114** of second substrate **7104** by surface mount soldering. End **6526** of first secondary winding **6514**, end **6528** of first secondary winding **6514**, end **6530** of second secondary winding **6516**, and end **6532** of second secondary winding **6516** are connected to a bottom surface **7112** of first substrate **7102** by surface mount soldering. In some alternate embodiments, the winding ends are connected to first substrate **7102** and/or second substrate **7104** by a method other than surface mount soldering, such as by through-hole pins soldered into plated through-holes in the substrates.

[0143] Each of first pin **7106** and second pin **7108** is disposed between first substrate **7102** and second substrate **7104** in first direction **202**. Each of first pin **7106** and second pin **7108** is formed, for example, of an electrically conductive material such as a metal, and each of first pin **7106** and second pin **7108** electrically couple first substrate **7102** and second substrate **7104**.

[0144] FIG. **73** illustrates in dashed lines outlines of winding ends that are connected to bottom surface **7112** of first substrate **7102**, where bottom surface **7112** is opposite of a top surface **7116** of first substrate. An electrical conductor **7124** of first substrate **7102** electrically couples end **6528** of first secondary winding **6514** to end **6530** of second secondary winding **6516**, thereby coupling first secondary winding **6514** and second secondary winding **6516** in series. An electrical conductor electrically **7126** couples end **6526** of first secondary winding **6514** to first pin **7106**, and an electrical conductor **7128** electrical couples end **6532** of second secondary winding **6516** to second pin **7108**. Each of electrical conductor **7124**, **7126**, and **7128** includes, for example, a PCB trace or a PCB conductive polygon.

[0145] Each of first switching stage **906** and second switching stage **908** is on a bottom outer surface **7118** of second substrate **7104**. First switching stage **906** is electrically coupled to end **6518** of first primary winding **6110**, and second switching stage **908** is electrically coupled to end **6522** of second primary winding **6512**. Capacitors **910** are located on bottom surface **7118** of second substrate **904**. In certain embodiments, capacitors **910** are electrically coupled to each of end **6520** of first primary winding **6510** and end **6524** of second primary winding **6512**.

[0146] In particular embodiments, magnetic device **6500**, first switching stage **906**, second switching stage **908**, and capacitors **910** of electrical assembly **7100** form part of a multi-phase switching power converter. For example, FIG. **74** is an electrical schematic diagram of a multi-phase switching power converter **7400** at least partially formed by elements of electrical assembly **7100**. It is understood, though, that electrical assembly **7100** is not limited to forming the FIG. **74** multi-phase switching power converter. Multi-phase switching power converter **7400** is similar to multi-phase switching power converter **1200** of FIG. **12** except that multi-phase switching power **7400** includes magnetic device **6500** in place of magnetic device **200**. FIG. **74** illustrates tuning inductor **1204** (not shown in FIGS. **71-73**) being on first substrate **7102** and controller **1206** (not shown in FIGS. **71-73**) being on second substrate **7104**. However, the respective locations of tuning inductor **1204** and controller **1206** in multi-phase switching power converter **7400** could vary without departing from the scope hereof.

Combinations of Features

[0147] Features described above may be combined in various ways without departing from the scope hereof. The following examples illustrate some possible combinations.

[0148] (A1) An electrical assembly includes a first substrate, a second substrate, a magnetic device disposed between the first substrate and the second substrate, and one or more electrical conductors on the first substrate. The magnetic device includes (1) a magnetic core, (2) a first primary winding extending through the magnetic core and electrically coupling the first substrate to the second substrate, (3) a second primary winding extending through the magnetic core and electrically coupling the first substrate to the second substrate, (4) a first secondary winding wound around at least a portion of the magnetic core, opposing ends of the first secondary winding being electrically coupled to the first substrate, and (5) a second secondary winding wound around at least a portion of the magnetic core, opposing ends of the second secondary winding being electrically coupled to the first substrate. The one or more electrical conductors on the first substrate electrically couple the first secondary winding in series with the second secondary winding.

[0149] (A2) The electrical assembly denoted as (A1) may further include (1) a first switching stage on the first substrate, where the first switching stage is electrically coupled to the first primary winding, and (2) a second switching stage on the first substrate, where the second switching stage is electrically coupled to the second primary winding.

[0150] (A3) In the electrical assembly denoted as (A2), the first switching stage, the second switching stage, and the magnetic device may collectively form at least part of a multi-phase switching power converter.

[0151] (A4) The electrical assembly denoted as (A1) may further include (1) a first switching stage on the second substrate, where the first switching stage is electrically coupled to the first primary winding, and (2) a second switching stage on the second substrate, where the second switching stage is electrically coupled to the second primary winding.

[0152] (A5) In the electrical assembly denoted as (A4), the first switching stage, the second switching stage, and the magnetic device may form at least part of a multi-phase switching power converter.
[0153] (A6) In any one of the electrical assemblies denoted as (A1) through (A5), the magnetic core may form a first winding window and a second winding window, each of the first primary winding and the first secondary winding may be wound through the first winding window, and each of the second primary winding and the second secondary winding may be wound through the second winding window.
[0154] (A7) In the electrical assembly denoted as (A6), the magnetic device may be disposed between the first substrate and the second substrate in a first direction, and each of the first winding window and the second winding window may extend through the magnetic core in the first direction.
[0155] (A8) In either one of the electrical assemblies denoted as (A6) or (A7), the first winding window may be separated from the second winding window in a second direction that is orthogonal to the first direction, the first primary winding may be separated from the first secondary winding in the first winding window in the second direction, and the second primary winding may be separated from the second secondary winding in the second winding window in the second direction.
[0156] (A9) In any one of the electrical assemblies denoted as (A1) through (A8), (1) the magnetic core may form a first gap in series with a magnetic flux path in the magnetic core magnetically coupling the first primary winding and the first secondary winding, the first gap being at least partially filled with a material having a lower magnetic permeability than a magnetic material forming the magnetic core, and (2) the magnetic core may form a second gap in series with a magnetic flux path in the magnetic core magnetically coupling the second primary winding and the second secondary winding, the second gap being at least partially filled with a material having a lower magnetic permeability than the magnetic material forming the magnetic core.
[0157] (A10) In any one of the electrical assemblies denoted as (A1) through (A9), the magnetic device may further include (1) a first ground conductor electrically coupling a ground node of the first substrate to a ground node of the second substrate and (2) a second ground conductor electrically coupling the ground node of the first substrate to the ground node of the second substrate.
[0158] (A11) In the electrical assembly denoted as (A10), the first ground conductor may be wound around the first secondary winding, and the second ground conductor may be wound around the second secondary winding.
[0159] (B1) An electrical assembly includes a first substrate, a second substrate, a first magnetic device disposed between the first substrate and the second substrate, a second magnetic device disposed between the first substrate and the second substrate, and one or more electrical conductors on the first substrate. The first magnetic device includes (1) a first magnetic core, (2) a first primary winding extending through the first magnetic core and electrically coupling the first substrate to the second substrate, and (3) a first secondary winding wound around at least a portion of the first magnetic core, where opposing ends of the first secondary winding are electrically coupled to the first substrate. The second magnetic device includes (1) a second magnetic core, (2) a second primary winding extending through the second magnetic core and electrically coupling the first substrate to the second substrate, and (3) a second secondary winding wound around at least a portion of the second magnetic core, where opposing ends of the second secondary winding are electrically coupled to the first substrate. The one or more electrical conductors on the first substrate electrically couple the first secondary winding in series with the second secondary winding.
[0160] (B2) The electrical assembly denoted as (B1) may further include (1) a first switching stage electrically coupled to the first primary winding and (2) a second switching stage electrically

coupled to the second primary winding, where the first switching stage, the second switching stage, the first magnetic device, and the second magnetic device collectively form at least part of a multi-phase switching power converter.

[0161] (B3) In either one of the electrical assemblies denoted as (B1) or (B2), (1) the first magnetic core may form a first winding window, (2) each of the first primary winding and the first secondary winding may be wound through the first winding window, (3) the second magnetic core may form a second winding window, and (4) each of the second primary winding and the second secondary winding may be wound through the second winding window.

[0162] (B4) In the electrical assembly denoted as (B3), (1) each of the first magnetic device and the second magnetic device may be disposed between the first substrate and the second substrate in a first direction, (2) the first winding window may extend through the first magnetic core in the first direction, (3) the second winding window may extend through the second magnetic core in the first direction, and (4) the second magnetic device may be separated from the first magnetic device in at least one of a second direction and a third direction, the second direction being orthogonal to the first direction, and the third direction being orthogonal to each of the first direction and the second direction.

[0163] (B5) In any one of the electrical assemblies denoted as (B1) through (B4), the first magnetic device may further include a first ground conductor electrically coupling a ground node of the first substrate to a ground node of the second substrate, and the second magnetic device may further include a second ground conductor electrically coupling the ground node of the first substrate to the ground node of the second substrate.

[0164] (C1) An electrical assembly includes a common substrate, a first additional substrate, a second additional substrate, a first magnetic device disposed between the common substrate and the first additional substrate, a second magnetic device disposed between the common substrate and the second additional substrate, and one or more electrical conductors on the common substrate. The first magnetic device includes a first magnetic core, a first primary winding extending through the first magnetic core and electrically coupling the common substrate to the first additional substrate, and a first secondary winding wound around at least a portion of the first magnetic core, where opposing ends of the first secondary winding are electrically coupled to the common substrate. The second magnetic device includes a second magnetic core, a second primary winding extending through the second magnetic core and electrically coupling the common substrate to the second additional substrate, and a second secondary winding wound around at least a portion of the second magnetic core, where opposing ends of the second secondary winding are electrically coupled to the common substrate. The one or more electrical conductors on the common substrate electrically couple the first secondary winding in series with the second secondary winding.

[0165] (C2) The electrical assembly denoted as (C1) may further include (1) a first switching stage electrically coupled to the first primary winding and (2) a second switching stage electrically coupled to the second primary winding, where the first switching stage, the second switching stage, the first magnetic device, and the second magnetic device collectively form at least part of a multi-phase switching power converter.

[0166] (C3) In either one of the electrical assemblies denoted as (C1) or (C2), (1) the first magnetic core may form a first winding window, (2) each of the first primary winding and the first secondary winding may be wound through the first winding window, (3) the second magnetic core may form a second winding window, and (4) each of the second primary winding and the second secondary winding may be wound through the second winding window.

[0167] (C4) In the electrical assembly denoted as (C3), (1) the first magnetic device may be disposed between the common substrate and the first additional substrate in a first direction, (2) the second magnetic device may be disposed between the common substrate and the second additional substrate in the first direction, (3) the first winding window may extend through the first magnetic core in the first direction, (4) the second winding window may extend through the second magnetic core in the first direction, and (5) the second magnetic device may be separated from the first magnetic device in at least one of a second direction and a third direction, the second direction being orthogonal to the first direction, and the third direction being orthogonal to each of the first direction and the second direction.

[0168] (D1) An electrical assembly includes a first substrate, a second substrate, a third substrate, a magnetic device disposed between the first substrate and the second substrate in a first direction, and one or more electrical conductors on the third substrate. The magnetic device includes (1) a first primary winding extending through the magnetic core and electrically coupling the first substrate to the second substrate, (2) a second primary winding extending through the magnetic core and electrically coupling the first substrate to the second substrate, (3) a first secondary winding wound around at least a portion of the magnetic core, opposing ends of the first secondary winding being electrically coupled to the third substrate, and (4) a second secondary winding wound around at least a portion of the magnetic core, opposing ends of the second secondary winding being electrically coupled to the third substrate. The one or more electrical conductors on the third substrate electrically couple the first secondary winding in series with the second secondary winding.

[0169] (D2) In the electrical assembly denoted as (D1), the third substrate may be over each of (i) the opposing ends of the first secondary winding and (ii) the opposing ends of the second secondary winding, in a direction orthogonal to the first direction.

[0170] (D3) In either one of the electrical assemblies denoted as (D1) or (D2), (1) a first end of the first primary winding may terminate on a first outer surface of the magnetic core, (2) a first end of the second primary winding may terminate on the first outer surface of the magnetic core, (3) a second end of the first primary winding may terminate on a second outer surface of the magnetic core, the second outer surface of the magnetic core being opposite of the first outer surface of the magnetic core, (4) the opposing ends of the first secondary winding may terminate on a third outer surface of the magnetic core, the third outer surface joining the first outer surface and the second outer surface in the first direction, and (5) the opposing ends of the of the second secondary winding may terminate on the third outer surface of the magnetic core.

[0171] (D4) Any one of the electrical assemblies denoted as (D1) through (D3) may further include (1) a first switching stage electrically coupled to the first primary winding and (2) a second switching stage electrically coupled to the second primary winding, where the first switching stage, the second switching stage, and the magnetic device collectively form at least part of a multi-phase switching power converter.

[0172] (D5) In any one of the electrical assemblies denoted as (D1) through (D4), (1) the magnetic core may form a first winding window extending through the magnetic core in the first direction, (2) each of the first primary winding and the first secondary winding may be wound through the first winding window, (3) the magnetic core may form a second winding window extending through the magnetic core in the second direction, and (4) each of the second primary winding and the second secondary winding may be wound through the second winding window.

[0173] (E1) An electrical assembly includes a first substrate, a second substrate, a magnetic device disposed between the first substrate and the second substrate in a first direction, and one or more electrical conductors on the first substrate. The magnetic device includes (1) a magnetic core, (2) a first primary winding extending through the magnetic core in a second direction that is orthogonal to the first direction, where opposing ends of the first primary winding are connected to the second substrate, (3) a second primary winding extending through the magnetic core in the second direction, where opposing ends of the second primary winding are connected to the second substrate, (4) a first secondary winding extending through the magnetic core in the second direction, where opposing ends of the first secondary winding are connected to the first substrate, and (5) a second secondary winding extending through the magnetic core in the second direction, where opposing ends of the second secondary winding are connected to the first substrate. The one

or more electrical conductors on the first substrate electrically couple the first secondary winding in series with the second secondary winding.
[0174] (E2) In the electrical assembly denoted as (E1), (1) the opposing ends of the first secondary winding and the opposing ends of the second secondary winding may terminate on a first outer surface of the magnetic core, and (2) the opposing ends of the first primary winding and the opposing ends of the second primary winding may terminate on a second outer surface of the magnetic core, where the second outer surface is opposite of the first outer surface.
[0175] (E3) Either one of the electrical assemblies denoted as (E1) or (E2) may further include (1) a first switching stage electrically coupled to the first primary winding and (2) a second switching stage electrically coupled to the second primary winding, where the first switching stage, the second switching stage, and the magnetic device collectively form at least part of a multi-phase switching power converter.
[0176] (E4) Any one of the electrical assemblies denoted as (E1) through (E3) may further include one or more pins disposed between the first substrate and the second substrate, where the one or more pins electrically couple the first substrate and the second substrate.
[0177] Changes may be made in the above methods, devices, and systems without departing from the scope hereof. It should thus be noted that the matter contained in the above description and shown in the accompanying drawings should be interpreted as illustrative and not in a limiting sense. The following claims are intended to cover generic and specific features described herein, as well as all statements of the scope of the present method and system, which as a matter of language, might be said to fall therebetween.

Claims

1. An electrical assembly, comprising: a first substrate; a second substrate; a magnetic device disposed between the first substrate and the second substrate, the magnetic device including: a magnetic core, a first primary winding extending through the magnetic core and electrically coupling the first substrate to the second substrate, a second primary winding extending through the magnetic core and electrically coupling the first substrate to the second substrate, a first secondary winding wound around at least a portion of the magnetic core, opposing ends of the first secondary winding being electrically coupled to the first substrate, and a second secondary winding wound around at least a portion of the magnetic core, opposing ends of the second secondary winding being electrically coupled to the first substrate; and one or more electrical conductors on the first substrate electrically coupling the first secondary winding in series with the second secondary winding.
2. The electrical assembly of claim 1, further comprising: a first switching stage on the first substrate, the first switching stage being electrically coupled to the first primary winding; and a second switching stage on the first substrate, the second switching stage being electrically coupled to the second primary winding.
3. The electrical assembly of claim 2, wherein the first switching stage, the second switching stage, and the magnetic device collectively form at least part of a multi-phase switching power converter.
4. The electrical assembly of claim 1, further comprising: a first switching stage on the second substrate, the first switching stage being electrically coupled to the first primary winding; and a second switching stage on the second substrate, the second switching stage being electrically coupled to the second primary winding.
5. The electrical assembly of claim 4, wherein the first switching stage, the second switching stage, and the magnetic device form at least part of a multi-phase switching power converter.
6. The electrical assembly of claim 1, wherein: the magnetic core forms a first winding window and a second winding window; each of the first primary winding and the first secondary winding are wound through the first winding window; and each of the second primary winding and the second

secondary winding are wound through the second winding window.

7. The electrical assembly of claim 6, wherein: the magnetic device is disposed between the first substrate and the second substrate in a first direction; and each of the first winding window and the second winding window extends through the magnetic core in the first direction.

8. The electrical assembly of claim 7, wherein the first winding window is separated from the second winding window in a second direction that is orthogonal to the first direction; the first primary winding is separated from the first secondary winding in the first winding window in the second direction; and the second primary winding is separated from the second secondary winding in the second winding window in the second direction.

9. The electrical assembly of claim 1, wherein: the magnetic core forms a first gap in series with a magnetic flux path in the magnetic core magnetically coupling the first primary winding and the first secondary winding, the first gap being at least partially filled with a material having a lower magnetic permeability than a magnetic material forming the magnetic core; and the magnetic core forms a second gap in series with a magnetic flux path in the magnetic core magnetically coupling the second primary winding and the second secondary winding, the second gap being at least partially filled with a material having a lower magnetic permeability than the magnetic material forming the magnetic core.

10. The electrical assembly of claim 1, wherein the magnetic device further includes: a first ground conductor electrically coupling a ground node of the first substrate to a ground node of the second substrate; and a second ground conductor electrically coupling the ground node of the first substrate to the ground node of the second substrate.

11. The electrical assembly of claim 10, wherein: the first ground conductor is wound around the first secondary winding; and the second ground conductor is wound around the second secondary winding.

12. An electrical assembly, comprising: a first substrate; a second substrate; a first magnetic device disposed between the first substrate and the second substrate, the first magnetic device including: a first magnetic core, a first primary winding extending through the first magnetic core and electrically coupling the first substrate to the second substrate, and a first secondary winding wound around at least a portion of the first magnetic core, opposing ends of the first secondary winding being electrically coupled to the first substrate; a second magnetic device disposed between the first substrate and the second substrate, the second magnetic device including: a second magnetic core, a second primary winding extending through the second magnetic core and electrically coupling the first substrate to the second substrate, and a second secondary winding wound around at least a portion of the second magnetic core, opposing ends of the second secondary winding being electrically coupled to the first substrate; and one or more electrical conductors on the first substrate electrically coupling the first secondary winding in series with the second secondary winding.

13. The electrical assembly of claim 12, further comprising: a first switching stage electrically coupled to the first primary winding; and a second switching stage electrically coupled to the second primary winding, wherein the first switching stage, the second switching stage, the first magnetic device, and the second magnetic device collectively form at least part of a multi-phase switching power converter.

14. The electrical assembly of claim 12, wherein: the first magnetic core forms a first winding window; each of the first primary winding and the first secondary winding are wound through the first winding window; the second magnetic core forms a second winding window; and each of the second primary winding and the second secondary winding are wound through the second winding window.

15. The electrical assembly of claim 14, wherein: each of the first magnetic device and the second magnetic device is disposed between the first substrate and the second substrate in a first direction; the first winding window extends through the first magnetic core in the first direction; the second winding window extends through the second magnetic core in the first direction; and the second magnetic device is separated from the first magnetic device in at least one of a second direction and a third direction, the second direction being orthogonal to the first direction, and the third direction being orthogonal to each of the first direction and the second direction.

16. The electrical assembly of claim 12, wherein: the first magnetic device further includes a first ground conductor electrically coupling a ground node of the first substrate to a ground node of the second substrate; and the second magnetic device further includes a second ground conductor electrically coupling the ground node of the first substrate to the ground node of the second substrate.

17. An electrical assembly, comprising: a common substrate; a first additional substrate; a second additional substrate; a first magnetic device disposed between the common substrate and the first additional substrate, the first magnetic device including: a first magnetic core, a first primary winding extending through the first magnetic core and electrically coupling the common substrate to the first additional substrate, and a first secondary winding wound around at least a portion of the first magnetic core, opposing ends of the first secondary winding being electrically coupled to the common substrate; a second magnetic device disposed between the common substrate and the second additional substrate, the second magnetic device including: a second magnetic core, a second primary winding extending through the second magnetic core and electrically coupling the common substrate to the second additional substrate, and a second secondary winding wound around at least a portion of the second magnetic core, opposing ends of the second secondary winding being electrically coupled to the common substrate; and one or more electrical conductors on the common substrate electrically coupling the first secondary winding in series with the second secondary winding.

18. The electrical assembly of claim 17, further comprising: a first switching stage electrically coupled to the first primary winding; and a second switching stage electrically coupled to the second primary winding, wherein the first switching stage, the second switching stage, the first magnetic device, and the second magnetic device collectively form at least part of a multi-phase switching power converter.

19. The electrical assembly of claim 17, wherein: the first magnetic core forms a first winding window; each of the first primary winding and the first secondary winding are wound through the first winding window; the second magnetic core forms a second winding window; and each of the second primary winding and the second secondary winding are wound through the second winding window.

20. The electrical assembly of claim 19, wherein: the first magnetic device is disposed between the common substrate and the first additional substrate in a first direction; the second magnetic device is disposed between the common substrate and the second additional substrate in the first direction; the first winding window extends through the first magnetic core in the first direction; the second winding window extends through the second magnetic core in the first direction; and the second magnetic device is separated from the first magnetic device in at least one of a second direction and a third direction, the second direction being orthogonal to the first direction, and the third direction being orthogonal to each of the first direction and the second direction.