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用户指南：  
**AN-8026: FAN9611 / FAN9612 400W  
1层评估板 (FEB-301)**

飞兆特色产品：  
FAN9611 / FAN9612

请将  
有关此评估板的问题或评论提交至：  
“全球支持中心”

[Fairchild Semiconductor.com](http://Fairchild Semiconductor.com)



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本用户指南支持FAN9611 / FAN9612 400W评估板，该评估板可用于交错式临界导通模式功率因数校正电源。本用户指南应当与FAN9611/FAN9611 / FAN9612数据手册以及飞兆半导体应用指南“[AN-6086 - 采用FAN9611 / FAN9612的交错式临界导通模式PFC的设计依据](#)”配合使用。用户指南和评估板还可用于评估具有更低导通阈值的FAN9611控制器。有关信息，请访问飞兆半导体网站[www.fairchildsemi.com](http://www.fairchildsemi.com)。

## 1. 评估板概述

FAN9611 / FAN9612交错式双临界导通模式(BCM)、功率因数校正(PFC)控制器可控制两个并行连接的180°异相升压系统。交错式功能可将控制技术的最大实际功率电平从大约300W扩展至800W以上。与常用于更高功率电平的连续导通模式(CCM)技术不同，BCM可以实现升压二极管的零电流开关(不产生反向恢复损耗)，这样就允许在不牺牲效率的情况下采用成本较低的二极管。此外，输入和输出滤波器的体积更小了，这是因为传动系统间纹波电流的降低以及开关频率的有效增倍。

带峰值检测的先进前馈线路可在线路瞬变时最大程度减少输出电压变化。为了确保在轻负载条件下稳定运行并具有较少的开关损耗，最大开关频率钳位在600kHz。在任何工作条件下都能保持同步。

内置保护功能有：输出过压保护、过流保护、反馈开路保护、欠压闭锁保护、掉电保护和冗余锁定过压保护。FAN9611 / FAN9612采用无铅16引脚SOIC封装。

飞兆半导体提供评估板，协助设计与测试采用FAN9611 / FAN9612的应用。FAN9611 / FAN9612评估板是单层板，针对400W (400V/1A)额定功率而设计。凭借相位管理功能，效率在低压线路和高压线路时保持在95%以上，甚至输出低至额定输出功率10%时也是如此。线路电压为115V<sub>AC</sub>和230V<sub>AC</sub>时，满载条件下的效率分别为96.3%和98.0%。

## 2. 通用规格

技术规格	最小值	最大值	单位
<b>输入</b>			
V <sub>in</sub> 交流电压	90	264	V <sub>AC</sub>
V <sub>in</sub> 交流频率	47	63	Hz
V <sub>DD</sub> 电源	13	16	V <sub>DC</sub>
<b>输出</b>			
输出电压		400	V
输出电流		1	A
<b>总输出功率</b>			
最大负载输出功率		400	W

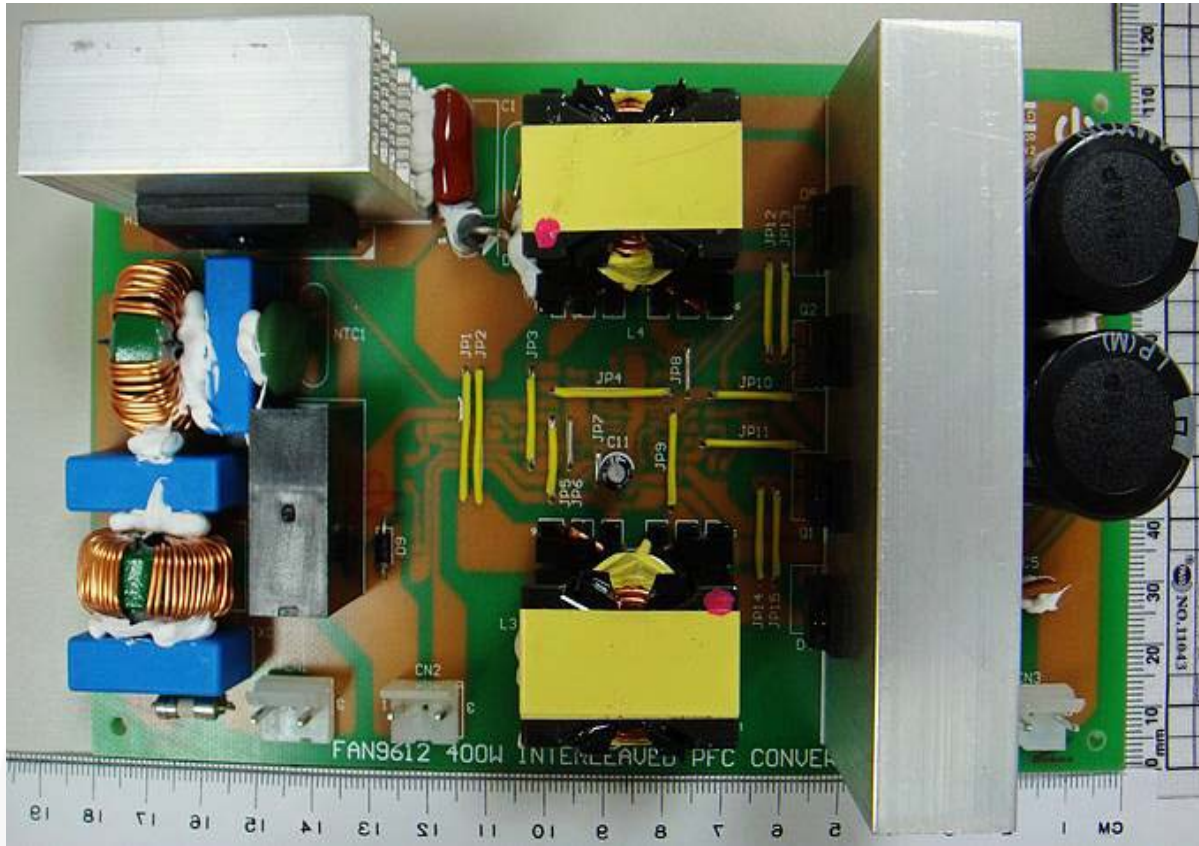
### 3. 测试步骤

测试评估板前，作为VDD的直流供电电压、作为线路输入的交流供电电压以及作为输出的直流电气负载应当与评估板正确连接。

1. 首先为控制芯片提供  $V_{DD}$ 。电压应高于 13V（参见  $V_{DD}$  导通阈值电压的规格）。
2. 提供  $V_{DD}$  时，继电器会发出“咔嚓”声。这是正常现象。由于浪涌电流限制继电器由 5V 参考电压（引脚 3）开启，因此通过提供高于 13V 的  $V_{DD}$  FAN9611 / FAN9612 可在退出 UVLO 时，开启继电器。
3. 连接交流电压 (90~264V<sub>AC</sub>) 以启动 FAN9611 / FAN9612。由于 FAN9611 / FAN9612 具有掉电保护和线路 OVP 功能，因此任何超出工作范围的输入电压都会触发保护。
4. 改变负载电流 (0~1A) 并检查工作状态。评估板设计为输出功率低于约 55W 时，即进入切相状态。输出功率超过 110W 左右时，即返回两路交错工作。

表 1. 测试设备

测试型号	FEB301-001
测试日期	2009年9月7日
测试温度	环境
测试设备	交流电源: Chroma 61603交流电源 电气负载: Chroma 63108 电表: WT210 示波器: Lecroy wavesurfer 24Xs 直流电源: ABM 9306D
测试项目	启动
	正常运行
	正常运行
	线路和负载瞬变
	通电/掉电保护
	相位管理
	效率
	谐波失真和功率因数



□ 1. 待测评估板照片

4. 原理图

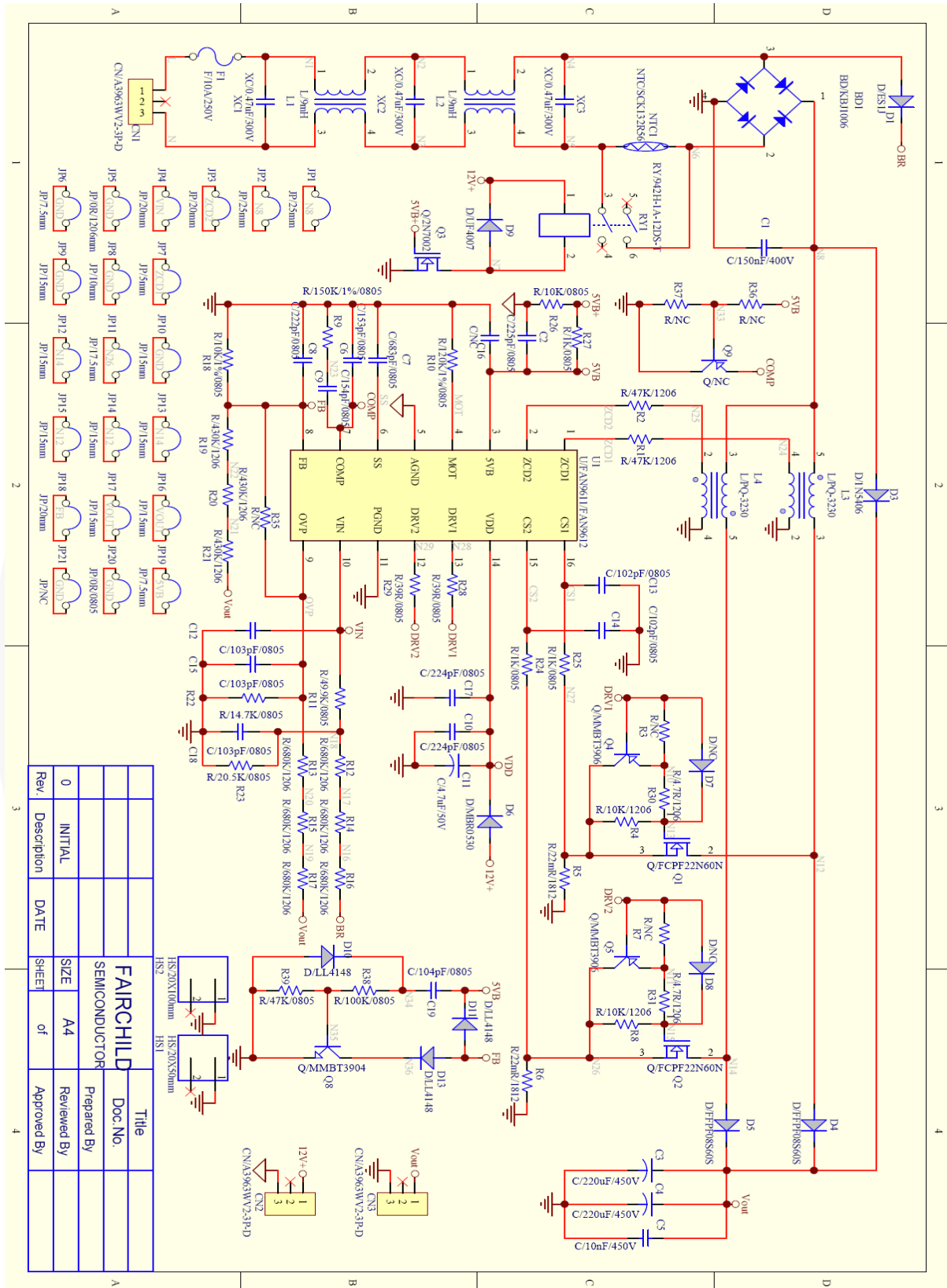
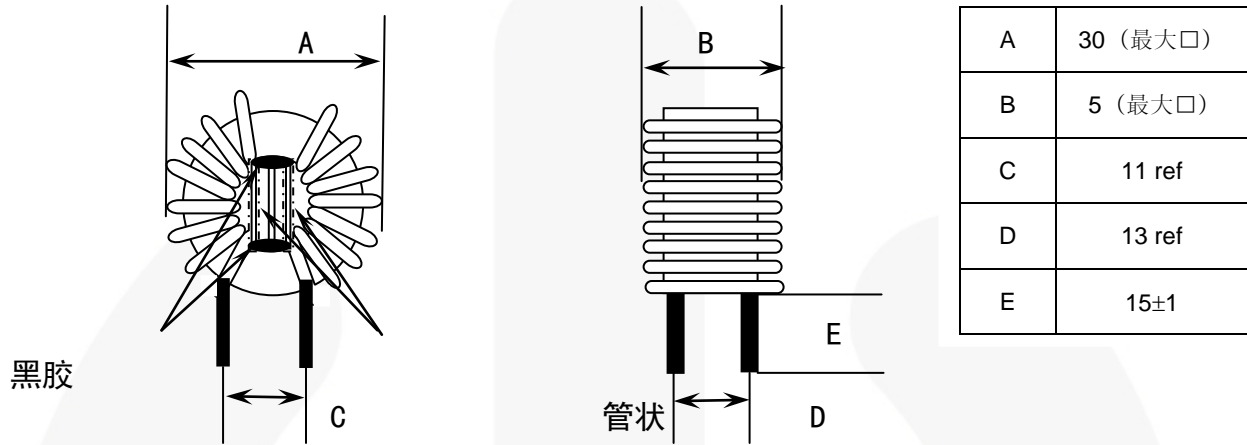


图 2. FAN9611 / FAN9612 400W评估板原理图

## 5. 规格认证

客户	飞兆半导体			P/N:	TRN-0197
日期	08/04/2006	版本	A	页	1/1

尺寸单位: mm



中间隔板厚度: 2mm  
(安全法规)

电气规范: 1kHz, 1V

电感: L1=L2: 9.0mH (最小值)  
DC电阻: L1=L2: 0.05Ω (最大值)  
匝数和导线: L1=L2: φ0.9 x 30.5TSx2

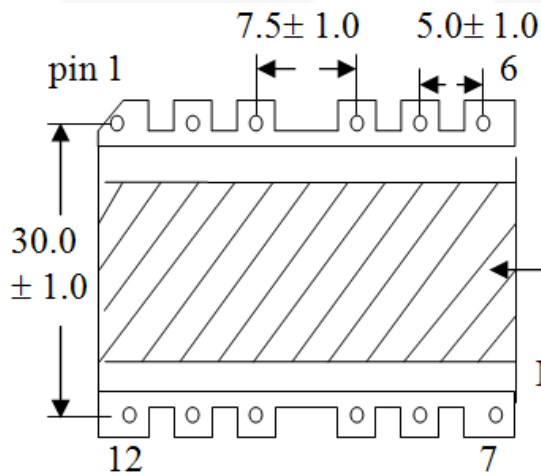
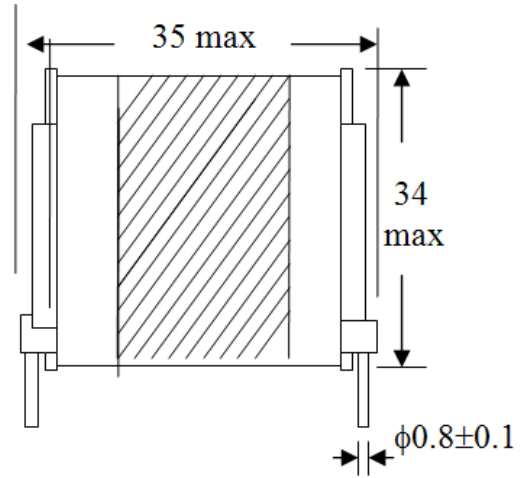
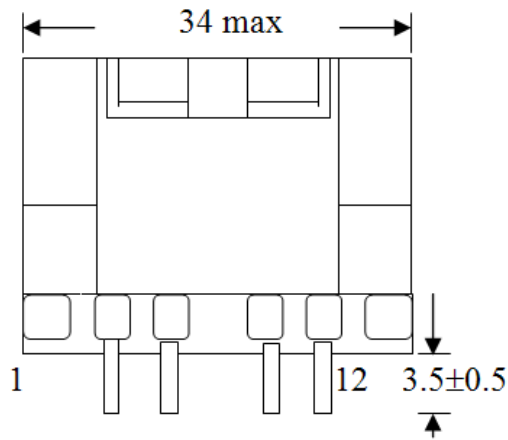
### 材料清单:

组件	材料	生产厂商	UL文件编号
1. 磁芯	T22x14x08	TOMITA	
2. 导线	THFN-216	Ta Ya Electric Wire Co., Ltd.	E197768
	UEWN/U	PACIFIC Wire & Cable Co., Ltd.	E201757
	UEWE	Tai-I Electric Wire & Cable Co., Ltd.	E85640
	UWY	Jang Shing Wire Co., Ltd.	E174837
3. 焊点	96.5% Sn, 3% Ag, 0.5% Cu,	Xin Yuan Co., Ltd.	

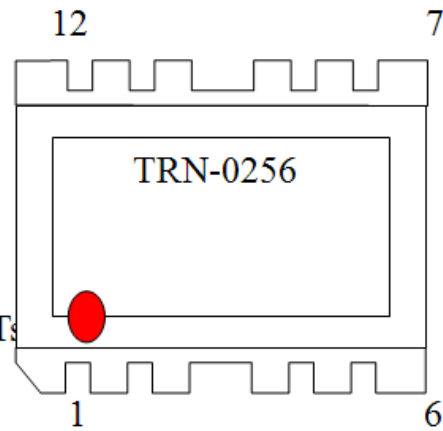
单位	m/m	作图	检查	标题	
电话	(02) 29450588	Ci wun Chen	Guo long Huang	IDENT#.	TRN-0197
传真	(02) 29447647	SEN HUEI INDUSTRIAL CO., LTD.		D W G#	10060
No. 26-1, Lane 128, Sec. 2, Singnan Rd., Jhonghe City, Taipei County 235, Taiwan (R.O.C.)					



客户	飞兆半导体			P/N:	TRN-0256
日期	09/02/2009	版本	A	页	1/4



Mylar Tape x3Ts



Bottom view

Top View

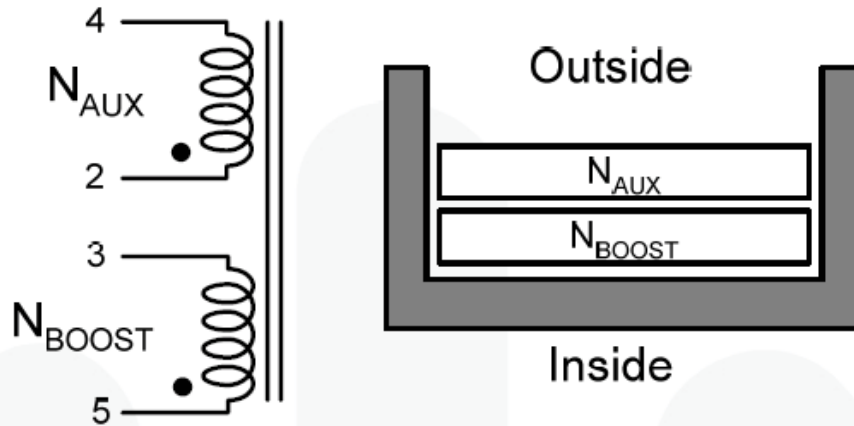
注:

1. 移除引脚1、6、7、8、10、11、12。
2. 增加绝缘带\*3的匝数以固定磁芯和线筒。
3. 红色符号表示第一个引脚。

单位	m/m	作图	检查	标题	
电话	(02) 2945-0588	Ci wun Chen	Guo long Huang	IDENT#	TRN-0256
传真	(02) 2944-7647	SEN HUEI INDUSTRIAL CO., LTD.		D W G#	I 3205
No. 26-1, Lane 128, Sec. 2, Singnan Rd., Jhonghe City, Taipei County 235, Taiwan (R. O. C.)					

客户	飞兆半导体			P/N:	TRN-0256
日期	09/02/2009	版本	A	页	3/4

## 6. 升压电感规格



	Pin	Diameter / Thickness	Turns
N1	5 → 3	0.1 mm × 100 (Litz wire)	30
Insulation Tape		0.05 mm	3
N2	2 → 4	0.2 mm	3
Insulation Tape		0.05 mm	3

Core : PQ3230 ( $A_e=161 \text{ mm}^2$ )  
 Bobbin: PQ3230  
 Inductance : 200 $\mu$ H

图 3. FAN9611 / FAN9612评估板中的升压电感

### 注意:

1. 引脚2、4、5增加卷管。

单位	m/m	作图	检查	标题	
电话	(02) 2945-0588	Ci wun Chen	Guo long Huang	IDENT#	TRN-0256
传真	(02) 2944-7647	SEN HUEI INDUSTRIAL CO., LTD.		D W G#	I3205
No. 26-1, Lane 128, Sec. 2, Singnan Rd., Jhonghe City, Taipei County 235, Taiwan (R. O. C.)					

## 6.1. 电气规范

### 电感测试： 1kHz, 1V

- P(5-3) : 200 $\mu$ H  $\pm$ 5%
- 直流电阻测试 ( $T_A = 25^\circ \text{C}$ )
- P(5-3) : 62.44m $\Omega$  (最大值)
- P(2-4) : 196.7m $\Omega$  (最大值)

### 耐压测试：

- 初级端和次级端之间 1000V / 60Hz / 0.5mA 交流耐压一分钟
- 初级端和磁芯之间 500V / 60Hz / 0.5mA 交流耐压一分钟

### 绝缘测试：

- 初级端和次级端之间以及绕组和磁芯之间的绝缘电阻在直流 500V 下测得，
- 必须超过 100M $\Omega$

### 端子强度：

- 对端子施加 1.0Kg 并持续 30 秒，测试击穿。

单位	m/m	作图	检查	标题	
电话	(02) 2945-0588	Ci wun Chen	Guo long Huang	IDENT#	TRN-0256
传真	(02) 2944-7647	SEN HUEI INDUSTRIAL CO., LTD.		D W G#	I3205
No. 26-1, Lane 128, Sec. 2, Singnan Rd., Jhonghe City, Taipei County 235, Taiwan (R. O. C.)					

客户	飞兆半导体			P/N:	TRN-0256
日期	09/02/2009	版本	A	页	3/4

**材料清单:**

组件	材料	生产厂商	文件编号
1. 骨架	酚醛树脂 94v-0, T373J, 150° C	PQ3230 Chang Chun Plastics Co., Ltd.	E59481 (S)
2. 磁芯	MB4	铁氧体磁芯PQ3230	
3. 导线	UEWE 130° C	Tai-I Electric Wire & Cable Co., Ltd.	E85640 (S)
	UEW-2 130° C	Jung Shing Wire Co., Ltd.	E174837
	UEW-B 130° C	Chuen Yih wire co., Ltd.	E154709 (S)
4. 涂料	BC-346A 180° C	John C Dolph Co., Ltd.	E51047 (M)
	468-2FC 130° C	Ripley Resin Engineering Co., Inc.	E81777 (N)
5. 卷带 0.025tmm	聚酯带, 3M #1350 130° C	Minnesota mining &MFG Co., Ltd.	E17385 (N)
	#31CT 130° C	Nitto Denko Corp.	E34833 (M)
6. 卷管	特氟龙卷管 TFS 600V, 200° C	Great Holding Industrial Co., Ltd.	E156256 (S)
7. 端子	覆锡- 铜线	Will Fore Special Wire Corp.	

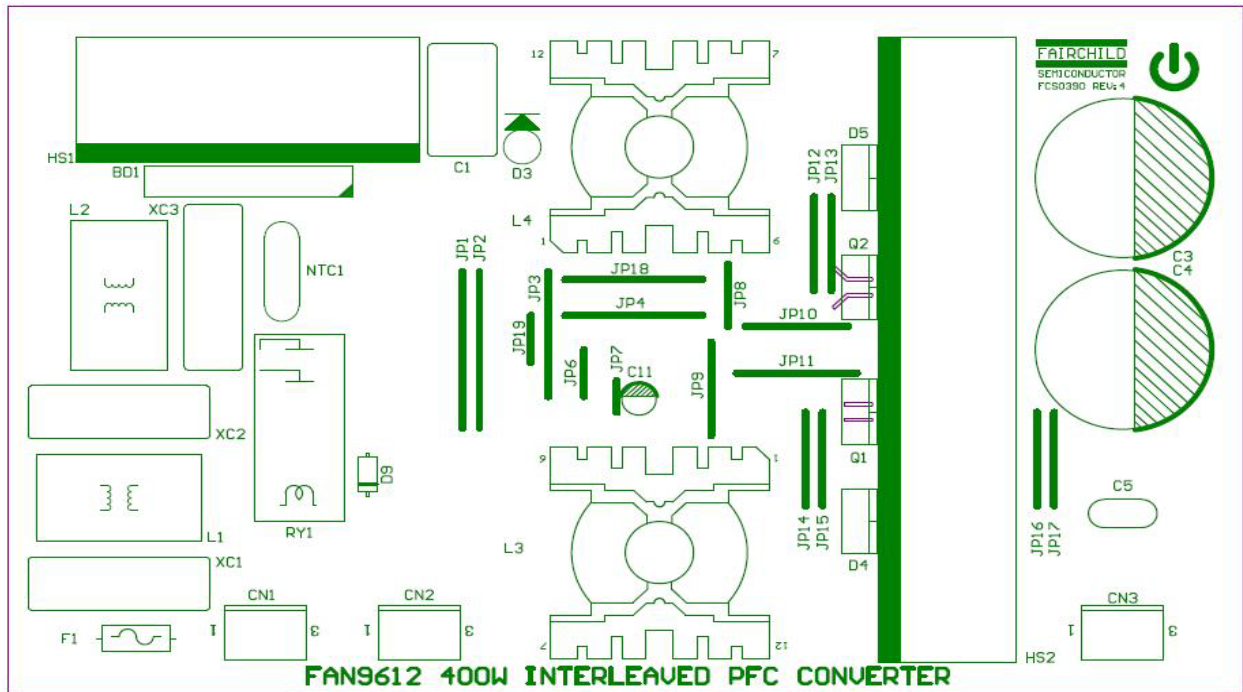
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电话	(02) 2945-0588	Ci wun Chen	Guo long Huang	IDENT#	TRN-0256
传真	(02) 2944-7647	SEN HUEI INDUSTRIAL CO., LTD.		D W G#	13205
No. 26-1, Lane 128, Sec. 2, Singnan Rd., Jhonghe City, Taipei County 235, Taiwan (R. O. C.)					

## 7. 材料单

组件	数量	部件编号	标号
跳线0.8 $\psi$ (mm)	18		JP1~ JP4 JP6~JP19
电阻0805 0 $\Omega$ +/-5%	1		JP20
电阻0805 39 $\Omega$ +/-5%	2		R28 R29
电阻0805 1K $\Omega$ +/-5%	3		R24 R25 R27
电阻0805 14K7 $\Omega$ +/-1%	1		R22
电阻0805 10K $\Omega$ +/-1%	2		R18 R26
电阻0805 20K5 $\Omega$ +/-1%	1		R23
电阻0805 47K $\Omega$ +/-5%	1		R39
电阻0805 49K9 $\Omega$ +/-1%	1		R11
电阻0805 100K $\Omega$ +/-5%	1		R38
电阻0805 120K $\Omega$ +/-1%	1		R10
电阻0805 150K $\Omega$ +/-1%	1		R9
电阻1206 0 $\Omega$ +/-5%	1		JP5
电阻1206 4 $\Omega$ +/-5%	2		R30 R31
电阻1206 10K $\Omega$ +/-5%	2		R4 R8
电阻1206 47K $\Omega$ +/-5%	2		R1 R2
电阻1206 430K $\Omega$ +/-5%	3		R19 R20 R21
电阻1206 680K $\Omega$ +/-5%	6		R12~R17
NTC13 $\psi$ 2 $\Omega$ SCK132	1		NTC1
电阻1812 0 $\Omega$ 022 +/-5%	2		R5 R6
0805 MLCC X7R +/-10% 102P 50V	2		C13 C14
0805 MLCC X7R +/-10% 103P 50V	3		C12 C15 C18
0805 MLCC X7R +/-10% 473P 50V	1		C19
0805 MLCC X7R +/-10% 104P 50V	1		C6
0805 MLCC X7R +/-10% 154P 25V	1		C9
0805 MLCC X7R +/-10% 222P 50V	1		C8
0805 MLCC X7R +/-10% 224P 50V	2		C10 C17
0805 MLCC X7R +/-10% 225P 25V	1		C2
0805 MLCC X7R +/-10% 683P 50V	1		C7

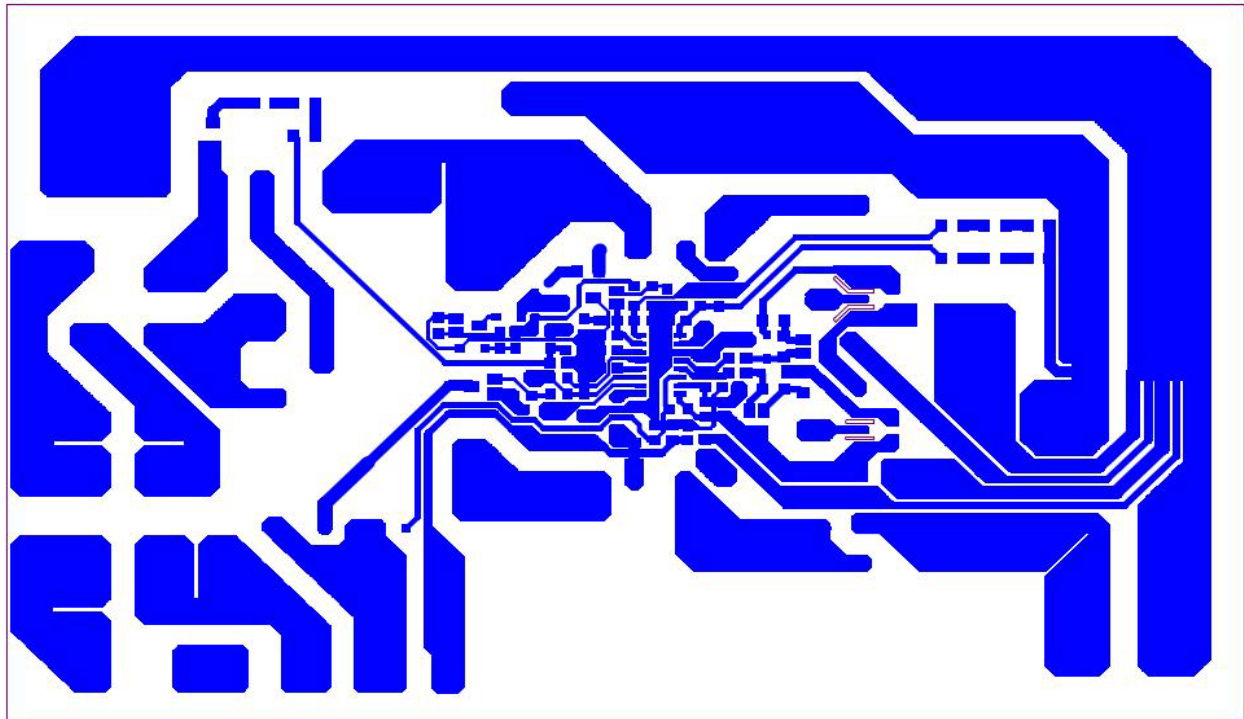
**材料清单 (续)**

组件	数量	部件编号	生产厂商	标号
陶瓷电容103P 500V +80/-20%	1			C5
电解电容47 $\mu$ 50V 105° C	1	LHK	JACKCON	C11
电解电容220 $\mu$ F 450V 105° C	2	LKP	JACKCON	C3 C4
MPP电容0.15 $\mu$ F 400V $\pm$ 5%	1	MPP154J2G15	ALL-RISE	C1
X1电容0.47 $\mu$ 300V +/-10%	3	SX1-S474-1K300S1	SHINY	XC1 XC2 XC3
共模噪声抑制	2	TRN0197	SEN HUEI	L1 L2
自定义电感PQ3230 L=200 $\mu$ H	2	TRN0256	SEN HUEI	L3 L4
整流器3A/600V D0-201AD	1	1N5406	飞兆半导体	D3
超快速恢复整流器1A/600V	1	ES1J	飞兆半导体	D1
超快速二极管1A/1000V D0-41	1	UF 4007	飞兆半导体	D9
SMD二极管LL4148	4			D7 D8 D10 D13
电桥10A/600V	1	KBJ1006	CP	BD1
SMD肖特基整流器0.5A/30V S0D-123	1	MBR0530	飞兆半导体	D6
整流器8A/600V T0-220F	2	FFPF08S60S	飞兆半导体	D4 D5
MOSFET, N沟道, 300mA/60V	1	2N7002	飞兆半导体	Q3
SMD NPN放大器	1	MMBT3904	飞兆半导体	Q8
SMD PNP放大器	2	MMBT3906	飞兆半导体	Q4 Q5
MOS 18A/500V T0-220F	2	FDPF18N50	飞兆半导体	Q1 Q2
保险丝, 陶瓷, 250V10A SLOW	1	37SG	SLEEK	F1
继电器942H-1A-12DS-T	1		BRIGHT TOWARD	RY1
晶圆(8639HS) 3-1P 3.96mm180°	3			CN1 CN2 CN3
HS 50(L)*50(H)*20(W)mm	1	MCH0597	SHUN TEH	HS1
HS 100(L)*50(H)*20(W)mm	1	MCH0598	SHUN TEH	HS2
IC FAN9611 / FAN9612 SMD	1	S01C-16	飞兆半导体	U1
PCB FCS0390修订版4	1		飞兆半导体	



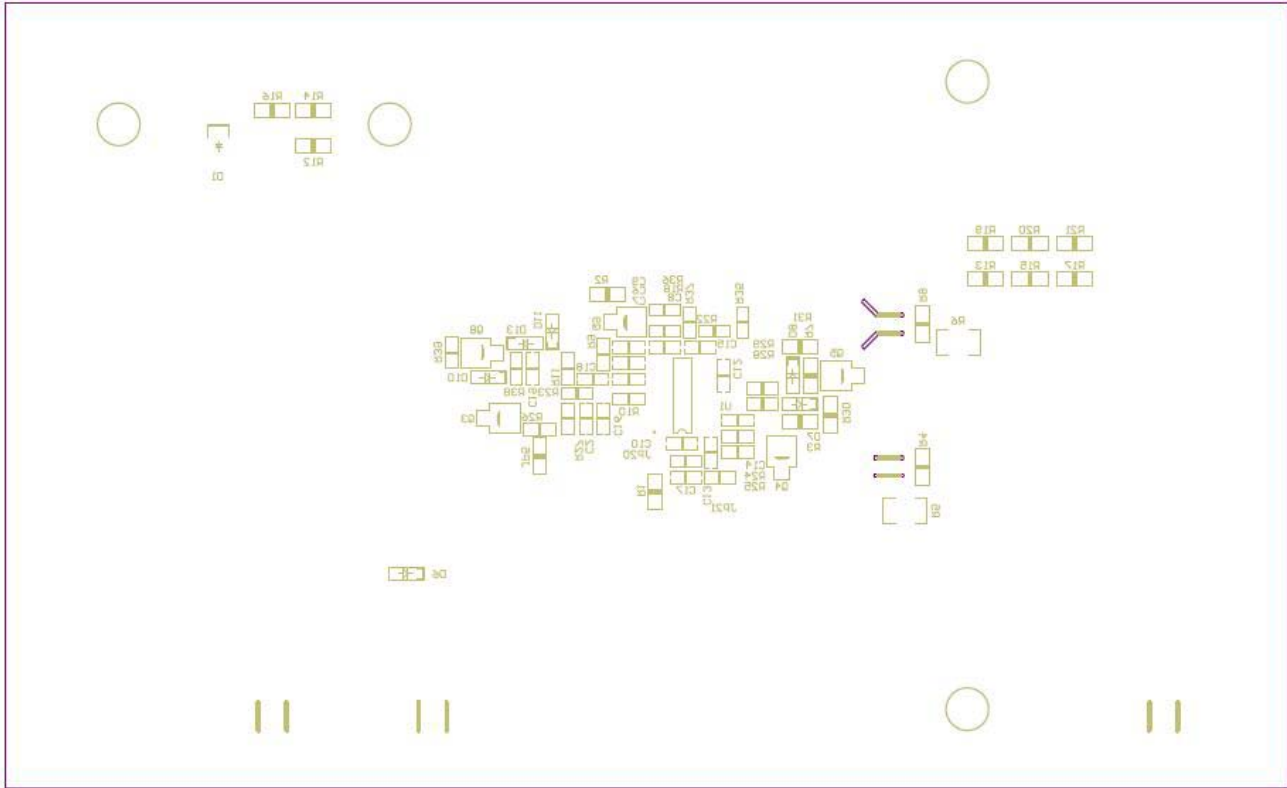
Top Overlay

图 4. PCB布局顶部覆盖层



Bottom Layer

图 5. PCB布局底层



Bottom Overlay

图 6. PCB布局底部覆盖层





## 8. 测试结果

### 8.1. 启动

测试条件：115V<sub>AC</sub> / 60Hz, 230V<sub>AC</sub> / 50Hz, 空载和满载。

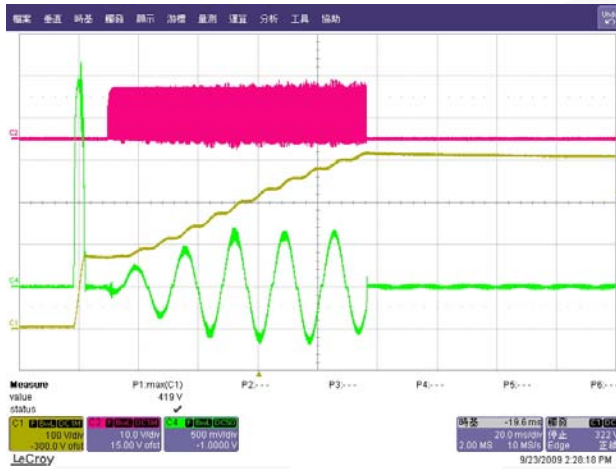


图 7. 115V<sub>AC</sub> / 60Hz (空载)

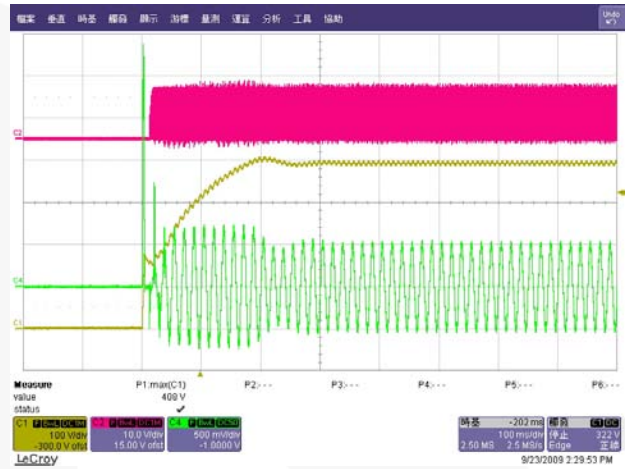


图 8. 115V<sub>AC</sub> / 60Hz (满载)

注意：

- 空载启动时，仅观察到29V（标称输出电压的7.44%）的过冲；而满载启动时仅观察到18V（标称输出电压的4.62%）的过冲。



图 9. 230V<sub>AC</sub> / 50Hz (空载)

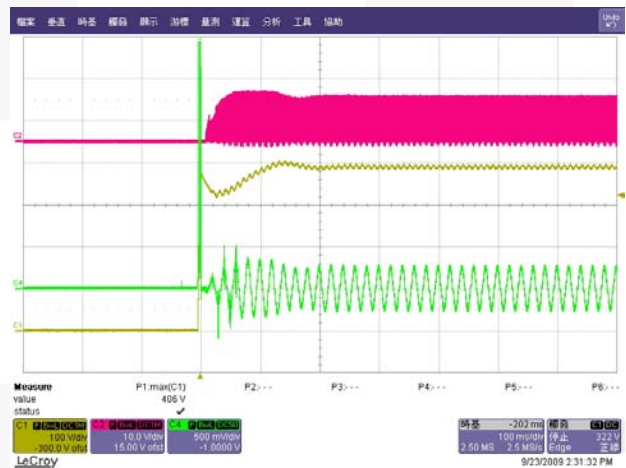


图 10. 230V<sub>AC</sub> / 50Hz (满载)

注意：

- 空载启动时，仅观察到17V（标称输出电压的4.36%）的过冲；而满载启动时仅观察到18V（标称输出电压的4.62%）的过冲。

## 8.2. 正常运行

测试条件：115V<sub>AC</sub> / 60Hz、230V<sub>AC</sub> / 50Hz满载时的电感电流。

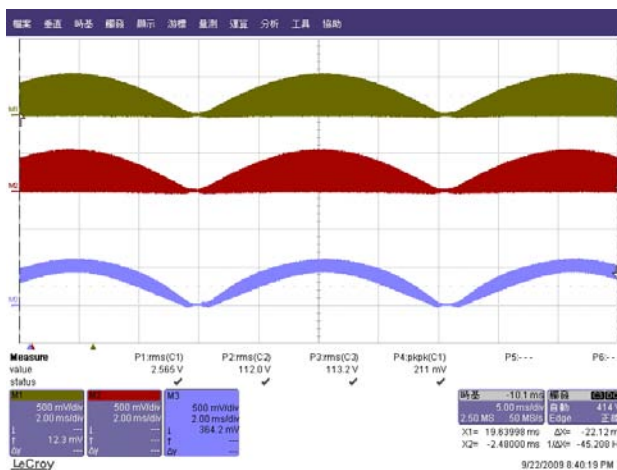


图 11. 115V<sub>AC</sub> / 60Hz (满载)

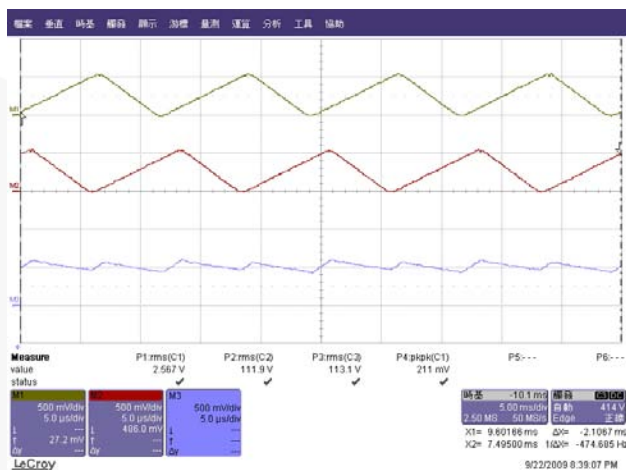


图 12. 115V<sub>AC</sub> / 60Hz (满载)

注意：

4. 图 11和图 12分别显示线路电压为115V<sub>AC</sub>时以及满载条件下两个电感的电流及两者之和。这两个电感的电流相加后，纹波电流相对较小，这是因为交错工作时纹波相消。

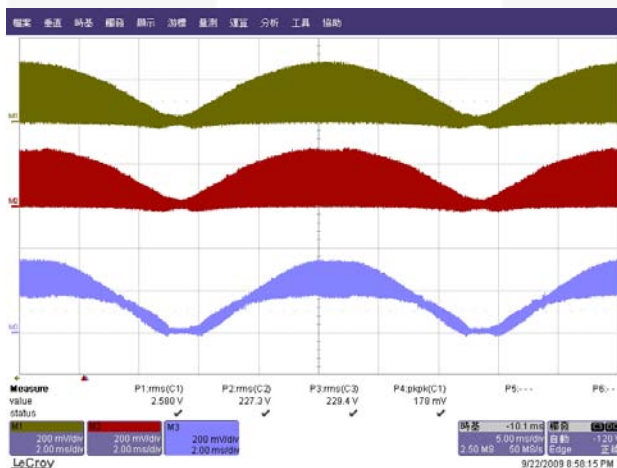


图 13. 230V<sub>AC</sub> / 50Hz (满载)

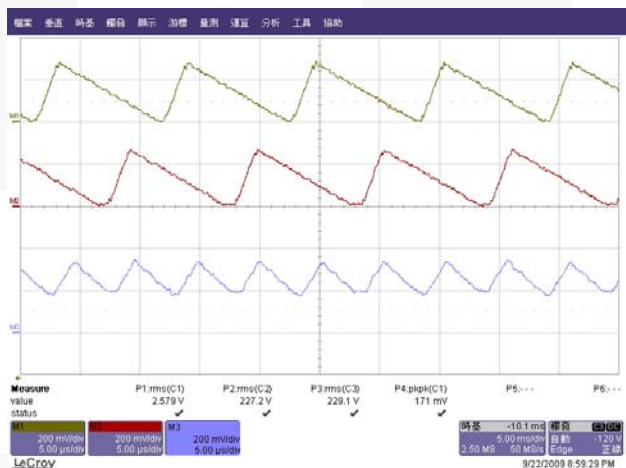


图 14. 230V<sub>AC</sub> / 50Hz (满载)

注意：

5. 图 13和图 14分别显示线路电压为230V<sub>AC</sub>时以及满载条件下两个电感的电流及两者之和。这两个电感的电流相加后，纹波电流相对较小，这是因为交错工作时纹波相消。

### 8.3. 线路和负载瞬变

测试条件：115V<sub>AC</sub>至230V<sub>AC</sub>满载瞬变和230V<sub>AC</sub>负载瞬变。

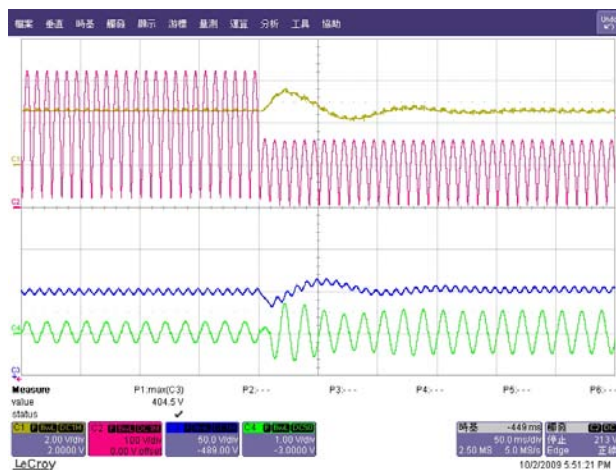


图 15. 230V<sub>AC</sub>至115V<sub>AC</sub>线路瞬变

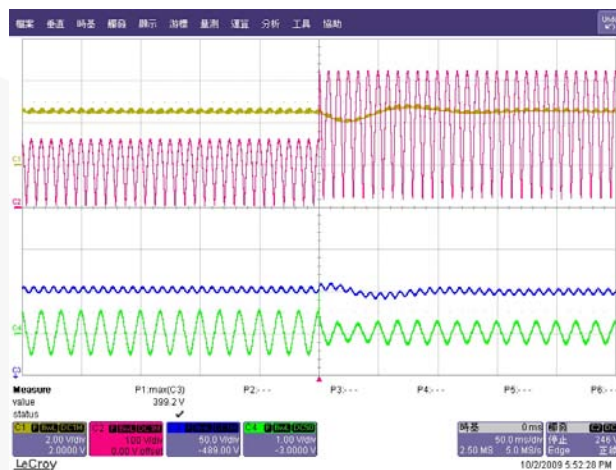


图 16. 115V<sub>AC</sub>至230V<sub>AC</sub>线路瞬变

注意：

6. 图 15和图 16显示的是因线路前馈功能使线路瞬变操作对输出电压的最小效应。线路电压从230V<sub>AC</sub>变为115V<sub>AC</sub>时，可观察到14.5V（标称输出电压的3.72%）的电压欠冲。线路电压从115V<sub>AC</sub>变为230V<sub>AC</sub>时，几乎观察不到有电压欠冲。

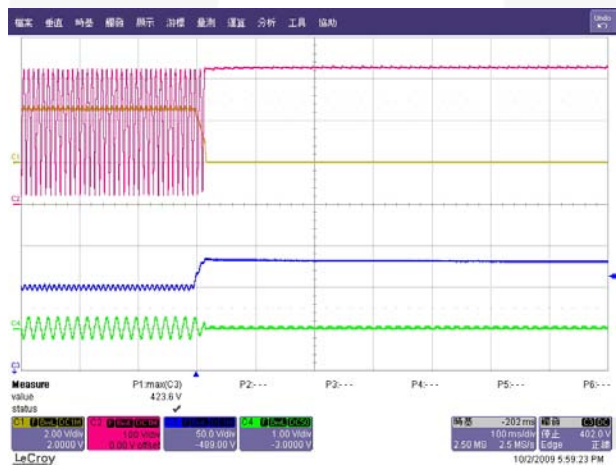


图 17. 230V<sub>AC</sub> 100%到0%线路瞬变

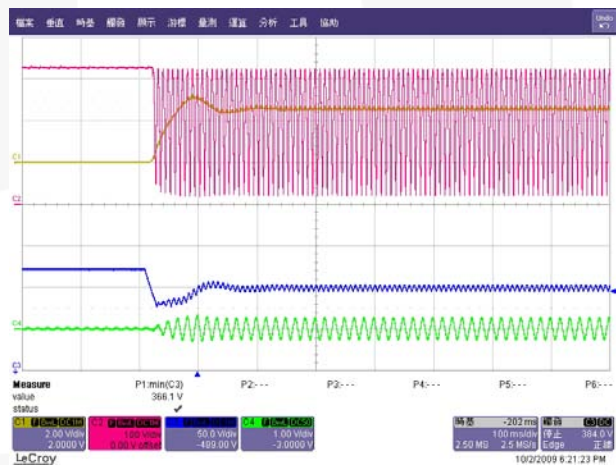


图 18. 230V<sub>AC</sub> 0%到100%线路瞬变

注意：

7. 图 17和图 18显示的是负载瞬变操作。输出负载从100%变为0%时，可观察到23.6V（标称输出电压的6.1%）的过冲。输出负载从0%变为100%时，可观察到23.9V（标称输出电压的6.13%）的欠冲。

## 8.4. 通电/掉电保护

测试条件： 缓慢增大和减小线路电压时开启和关断。

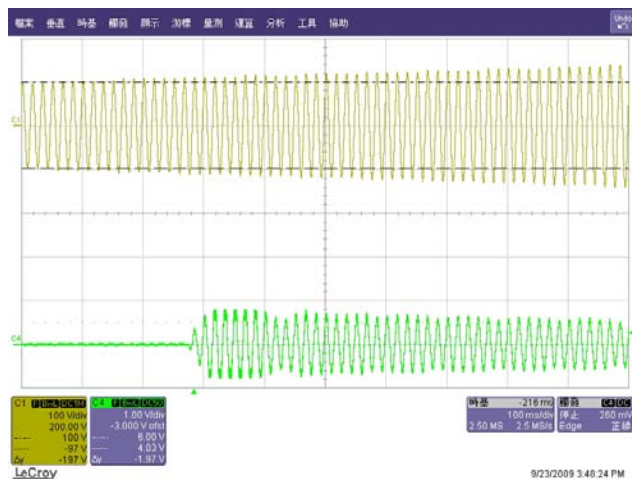


图 19. 通电

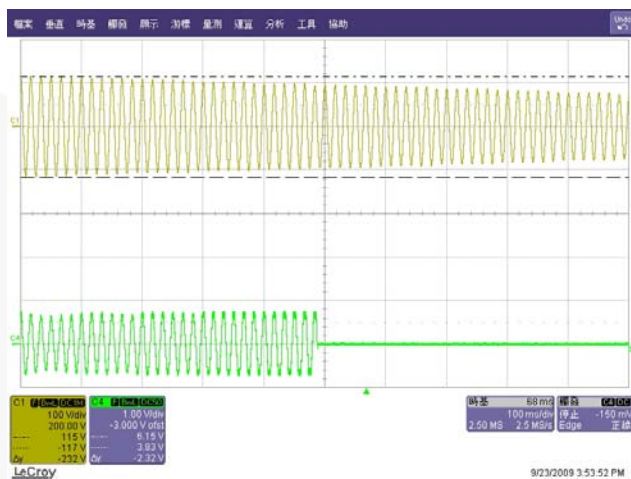


图 20. 欠压

**注意:**

- 图 19和图 20分别显示的是线路电压缓慢增大和缓慢减小时的启动与关断操作。线路电压达到约 $80V_{AC}$ 时，电源开启；线路电压下降至 $70V_{AC}$ 以下时，电源关断。

## 8.5. 相位管理

测试条件：改变输出负载，观察切相和相位叠加。

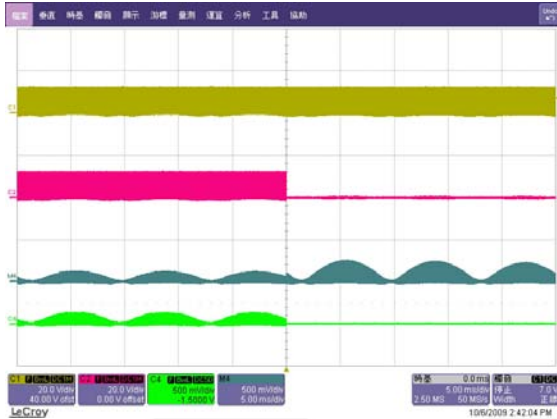


图 21. 切相

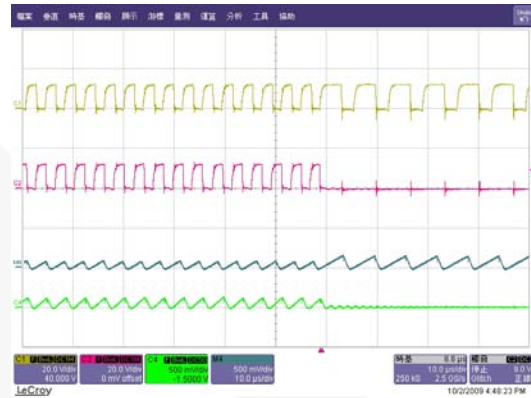


图 22. 放大

注意：

9. 图 21和图 22显示的是切相波形。沟道1栅极驱动信号的占空比在其他通道栅极驱动信号禁用时倍增，实现最少的线路电流干扰。



图 23. 相位叠加

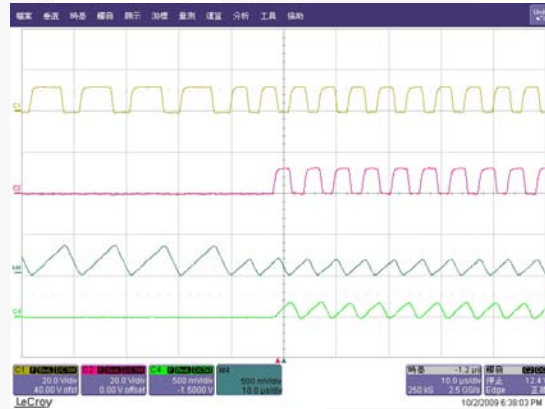


图 24. 放大

注意：

10. 图 23和图 24显示的是相位叠加波形。沟道1栅极驱动信号的占空比在其他通道栅极驱动信号使能前减半，实现最少的线路电流干扰。

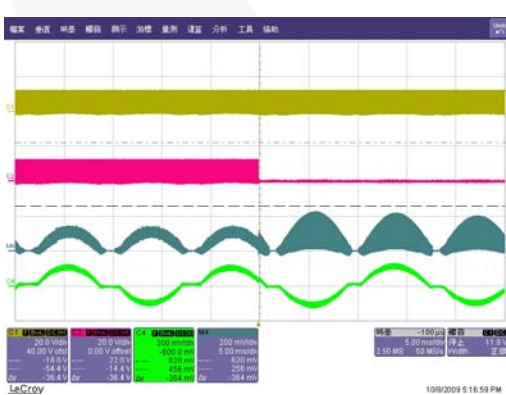


图 25. 切相和线路电流

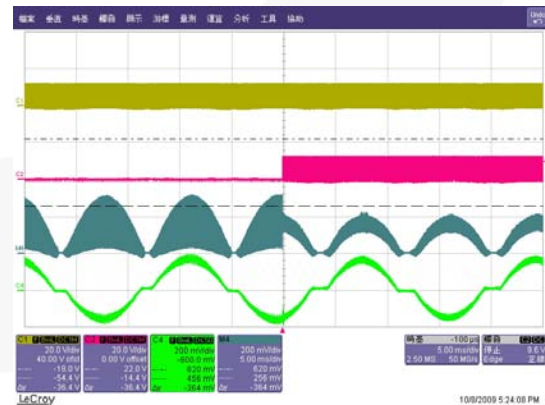


图 26. 相位叠加和线路电流

注意：

11. 图 25和图 26分别显示的是两个电感的电流之和以及切相和相位叠加时的线路电流。如图所示，相位管理功能未明显改变线路电流波形。

## 8.6. 效率

测试条件：115V<sub>AC</sub> / 60Hz和230V<sub>AC</sub> / 50Hz效率。

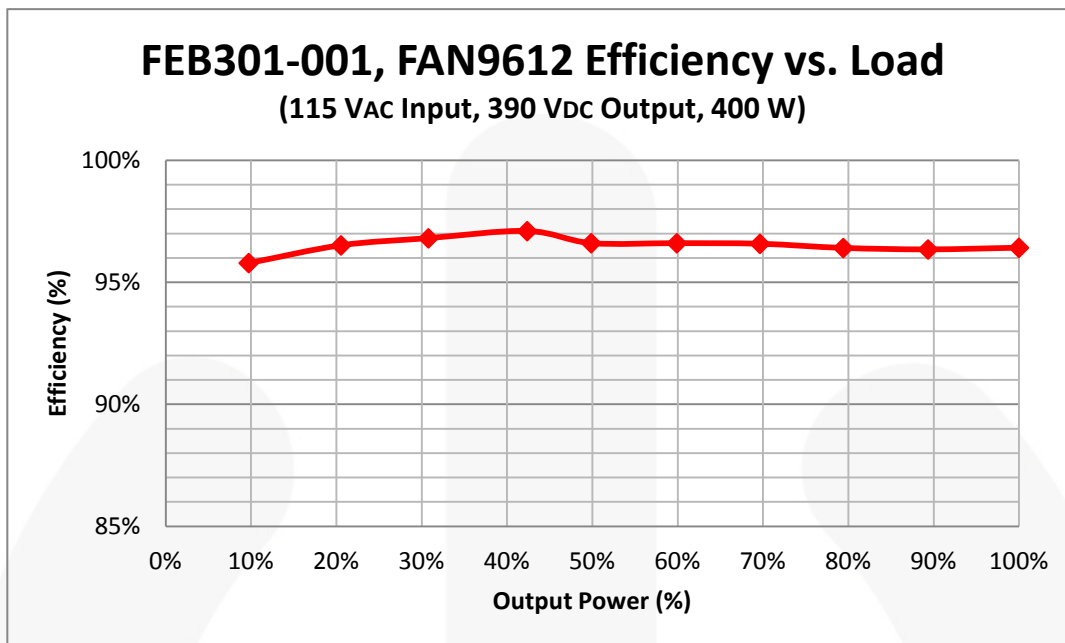


图 27. 115V<sub>AC</sub> / 60Hz效率与 负载的关系

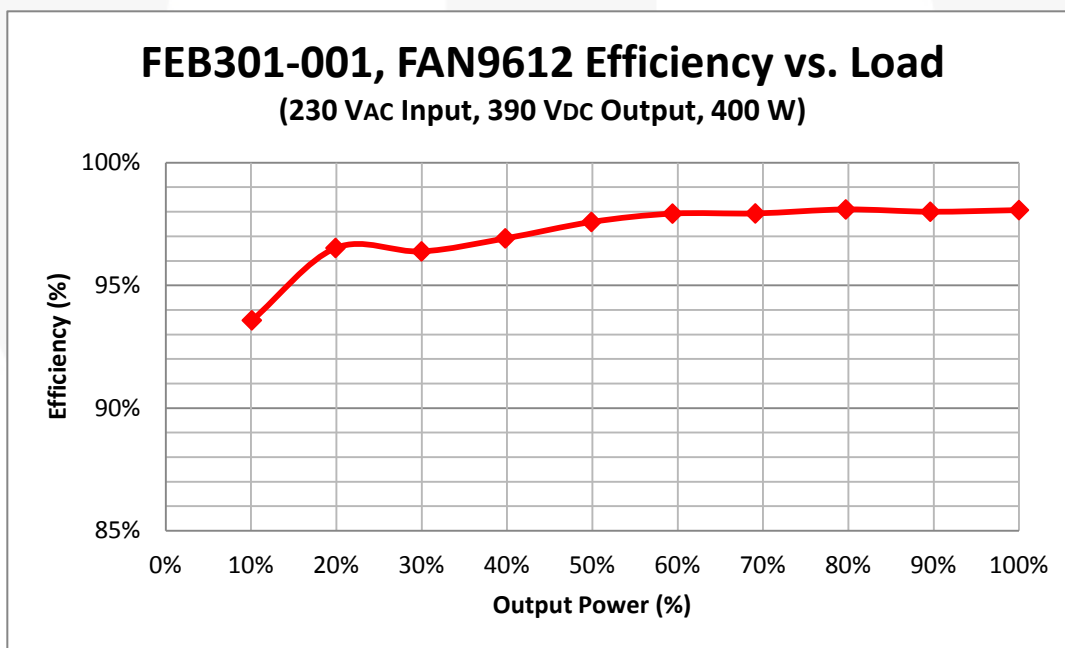


图 28. 230V<sub>AC</sub> / 50Hz效率与 负载的关系

**注意：**

12. 图 27和图 28显示的是输入电压分别为115V<sub>AC</sub>和230V时，测得的评估板的效率。由于切相通过有效降低轻载时的开关频率可减少开关损耗，因此在开关损耗较高的高压线路上，效率能提高更多。低压线路上的效率相对提高较少，这是因为MOSFET以零电压开启，开关损耗忽略不计。

## 8.7. 谐波失真和功率因数

测试条件： 测量115V<sub>AC</sub> / 60Hz和230V<sub>AC</sub> / 50Hz输出满载条件下的谐波与功率因数。

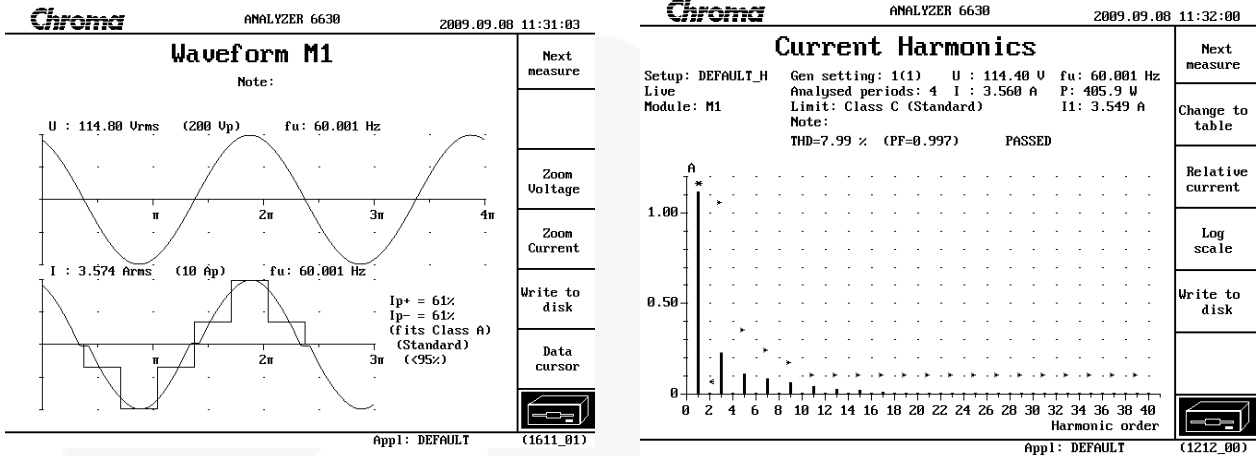


图 29. 115V<sub>AC</sub>/60Hz, 输出满载

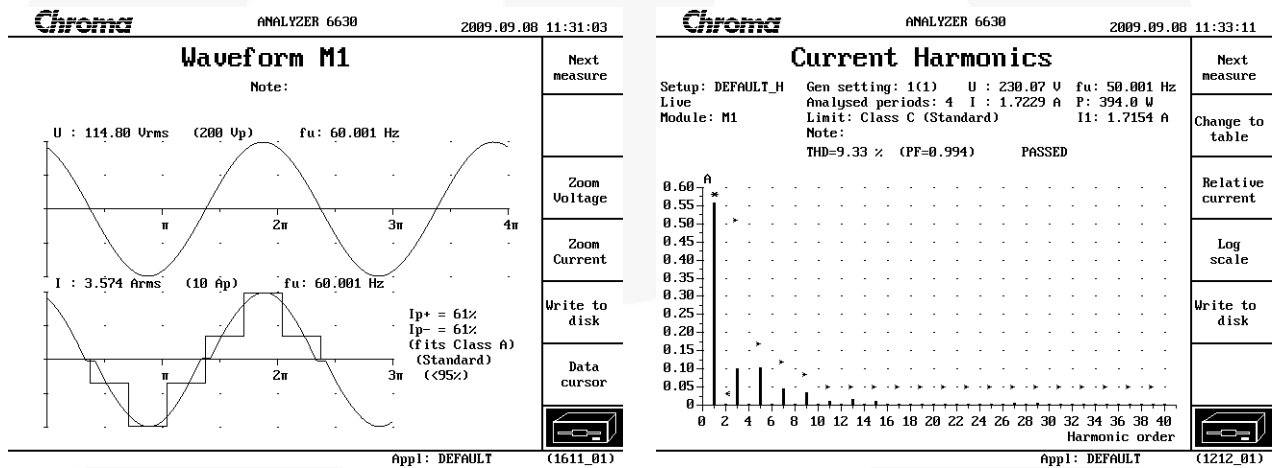


图 30. 230V<sub>AC</sub>/50Hz, 输出满载

注意:

13. 分别采用EN61000 D类和C类规范比较输入电压为115V<sub>AC</sub>和230V<sub>AC</sub>时测得的谐波电流。D类适用于电视机和PC电源，C类适用于照明应用。从图中可以看出，两种规范均得到了满足，且裕量足够。

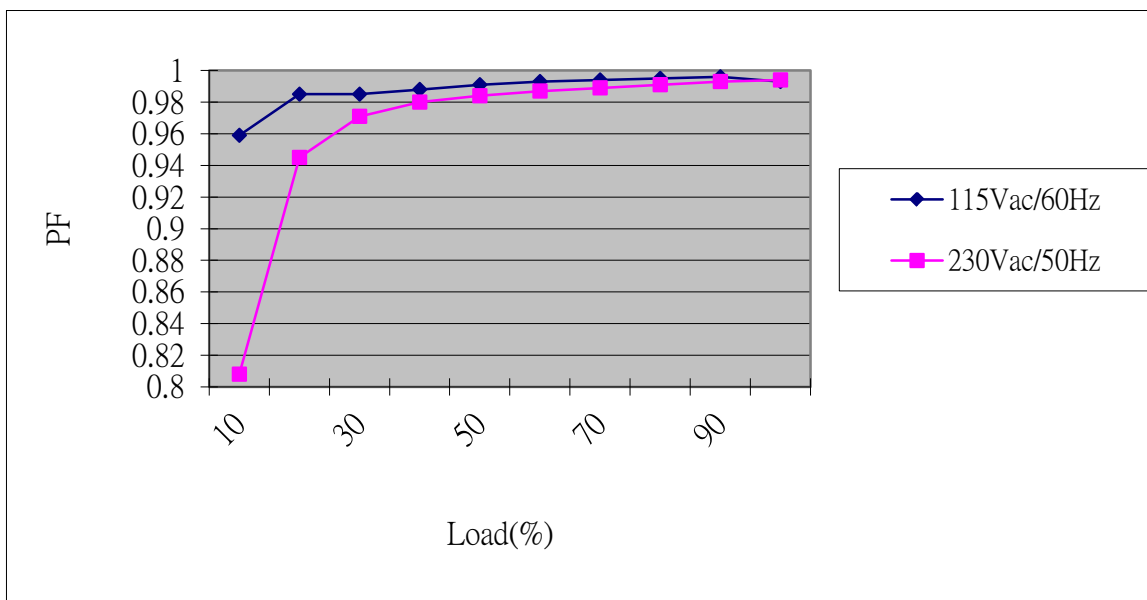


图 31. 测得的功率因数

表 2. 输入电压为115V<sub>AC</sub>和230V<sub>AC</sub>时的总谐波失真

	50%	75%	100%
115V <sub>AC</sub> / 60Hz	12.88	9.91	7.99
230V <sub>AC</sub> / 50Hz	13.06	11.47	9.33



## 9. 参考文献

[FAN9611 / FAN9612 - 交错式双BCM PFC控制器](#)

[AN-6086 - 采用FAN9611 / FAN9612的交错式临界导通模式 \(BCM\) PFC的设计依据](#)

[AN-8018 - FAN9611 / FAN9612 400W交错式双BCM PFC控制器 评估板用户指南](#)

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