开关电源电磁兼容及其研究新进展
Review on EMC studies of SMPS

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Oct, 31, 2008
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内　容

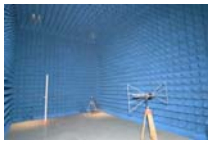
一.开关电源技术发展面临的EMC挑战

*随着人们对清洁环境、生活品质要求不断提高，全球主要国家对电气、电子产品**电磁兼容性的要求日益严格！***

欧盟　美国　中国　加拿大

开关电源大电压、电流跳变工作易产生强烈的电磁干扰！

开发周期延长、体积增加、成本上升！



辐射发射测试

传导发射测试

Oct, 31, 2008 Hejunping

开关电源继续向***高频化、高功率密度化、数字化、高效、低成本***方向迅速发展！

LDMOS：5MHz-10MHz　*vs.*　MESFET/HEMT：50MHz

Vicor/2MHz/200W

Nujira/10MHz/300W

Delta/3kW/700kHz

Power density：DC/DC 200 W/inch3 vs. AC/DC 1000W/inch^3

Vicor/PRM

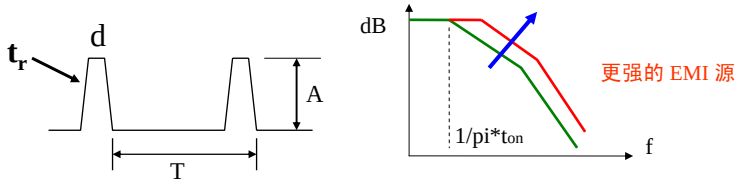
Delta//3kW/700kHz

Digital controller：clock frequency 20MHz-100MHz

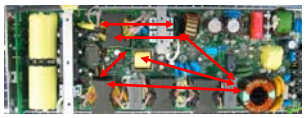
TI/DSP 2808

电磁兼容设计面临着新挑战！

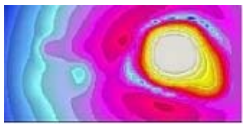
更高的工作频率、更高的dv/dt、di/dt，**更强高频频谱！**



更近的距离，更强的电磁耦合，**更加复杂电磁干扰形成和传播！**



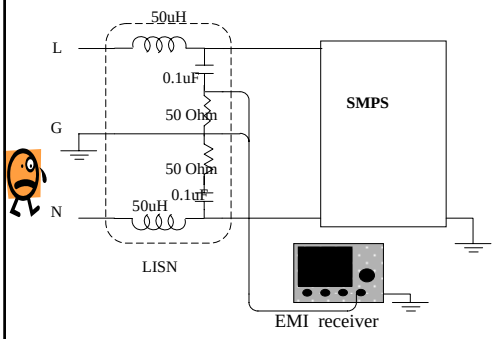
Telecom PS



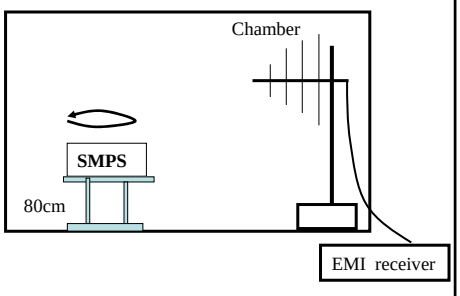
Magnetic field

需要对干扰形成机制、预测、抑制和设计技术进行大力研究和实践！

二.开关电源电磁干扰发射的形成和传播



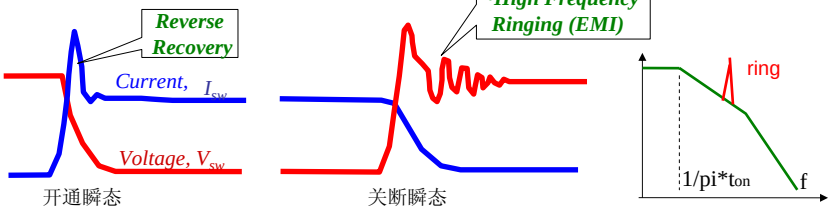
传导测试测试



辐射发射测试

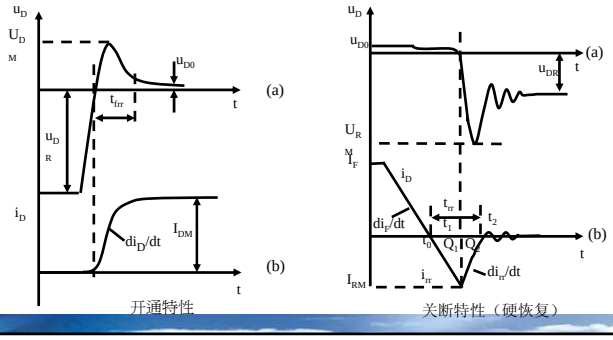
2.1 电磁干扰的源头

A：功率晶体管



开通瞬态　　关断瞬态

B：功率二极管



开通特性　　关断特性（硬恢复）

2.2 电磁干扰的形成和传播

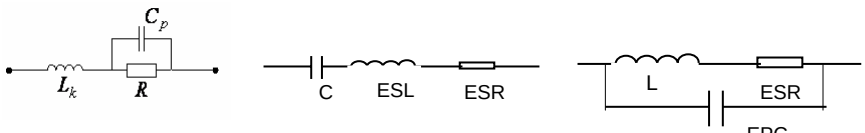
电磁干扰传播的机理

*A：沿着主电路、输入/输出线及其寄生参数传播，**与主功率回路相同；***

*B：沿着杂散电磁耦合通道传播，**隐蔽！***

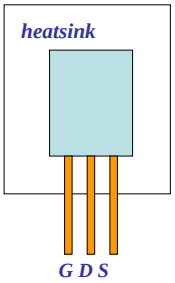
*C：直接向周围空间辐射传播，**复杂！***

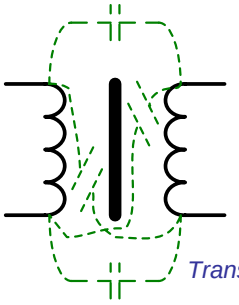
无源器件的高频寄生参数

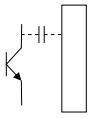


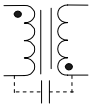
电阻器　　电容器　　电容器

杂散电磁耦合参数

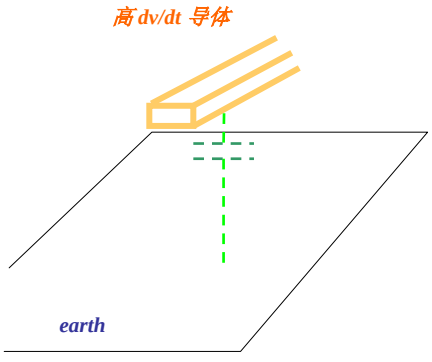


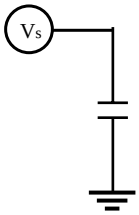




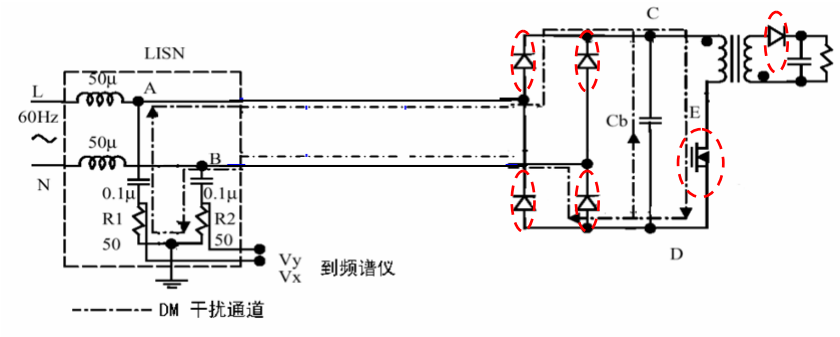


杂散耦合参数



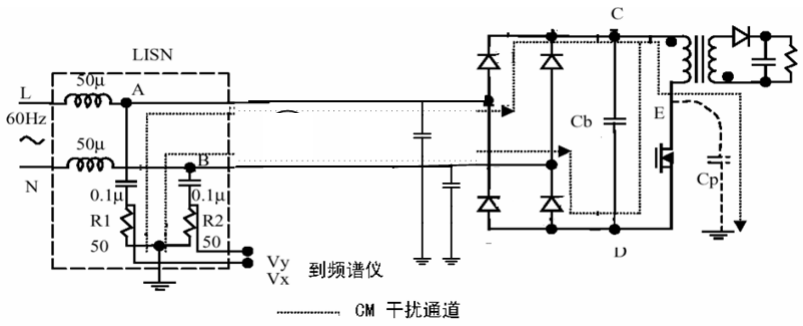


传导干扰发射的形成和传播

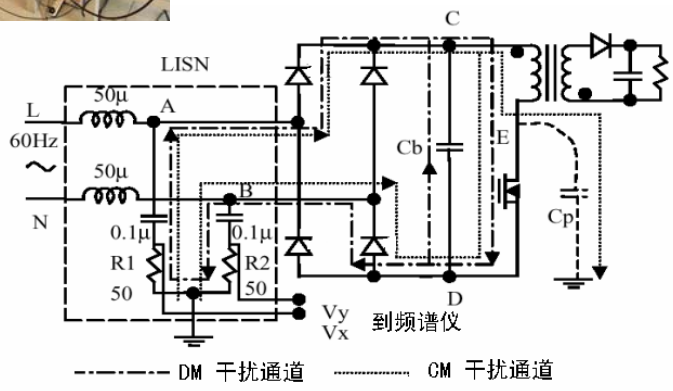


Flyback DM

高dv/dt导体面积
一定要尽可能小

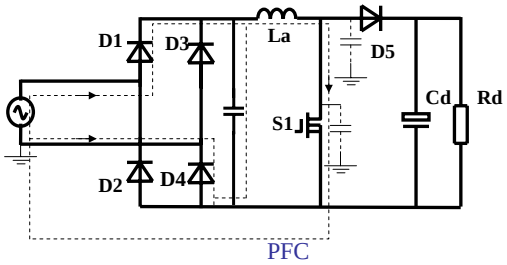


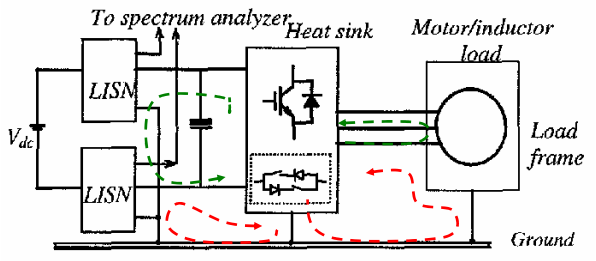
Flyback CM



Flyback total

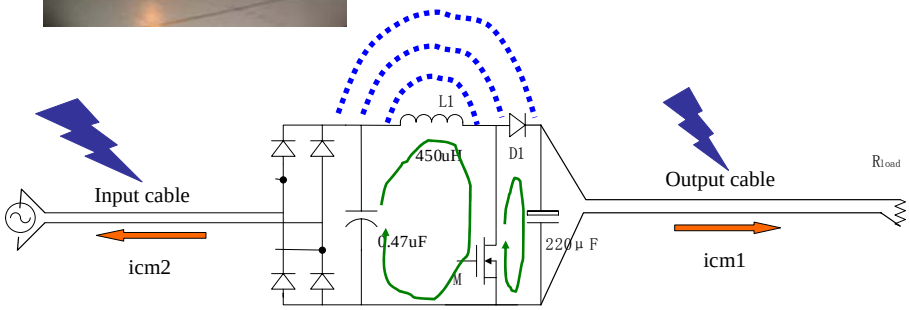
CM/DM分析也是分析其它拓扑结构电源的有效方法！





Inverter

辐射干扰的形成和传播

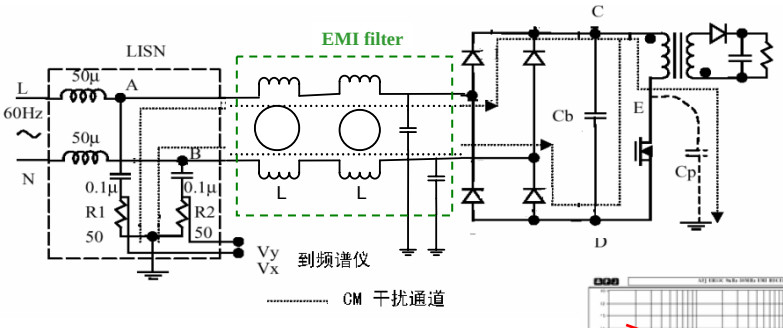


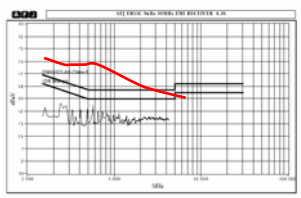
PFC

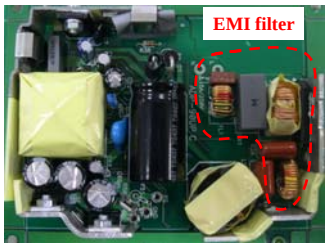
三.开关电源电磁干扰发射的抑制

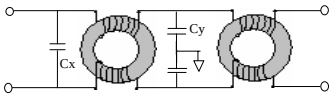
A：EMI滤波器：可靠、基础性办法

无源LC反射滤波或吸收滤波，可覆盖150kHz-1GHz。









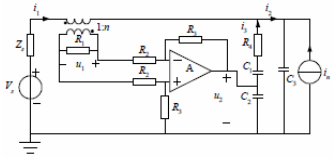
Adapter EMI filter

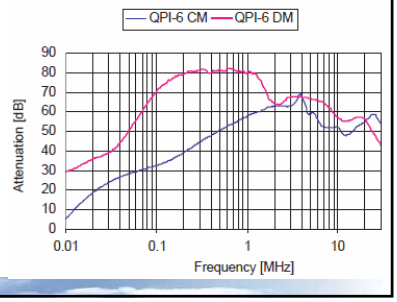
- EMI滤波器应处于阻抗失配状态
- 电感、电容应有足够的电压、电流容量
- Ldm电感、Cx、Cy电容有最大值限制

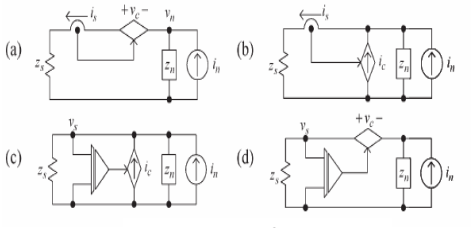
有源滤波器，可在150kHz-几MHz有效

Active EMI filter for DC/DC

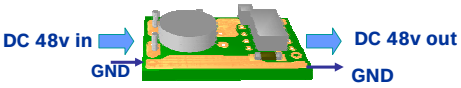
Picor Com





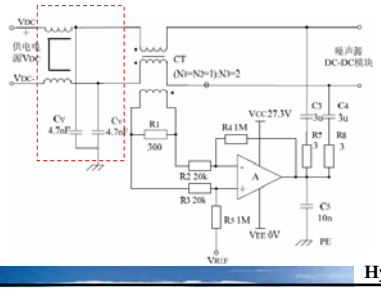


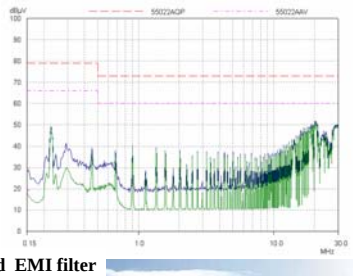
ALL active EMI filter topology



Delta/ Xjtu/

Emerison/ Hit

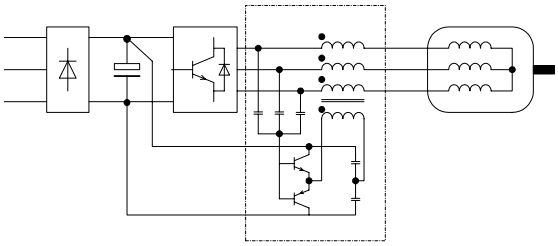


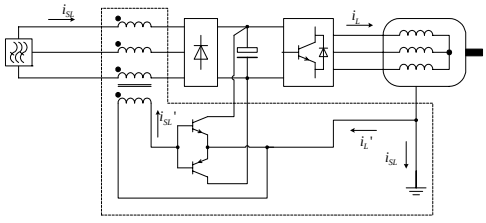


Hybird EMI filter

也用于逆变电源

Active Common Mode Noise Canceller

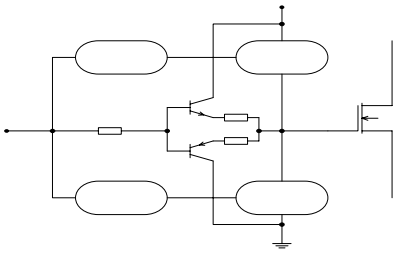


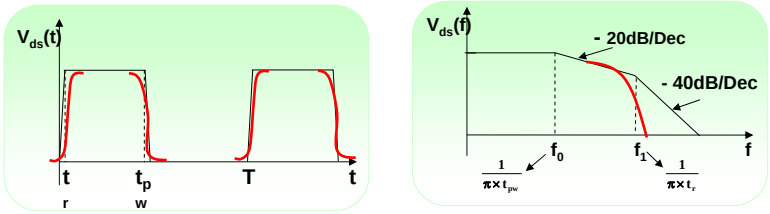


Active EMI Filter

B：根据电源拓扑、结构、控制等多种方面，采用新型抑制方法

B1:改善门极驱动





适当的驱动可使功率损耗和高频频谱得到平衡

已商业化。

Monostable 1

Additi
Curr
Gener

Rgon

Rgoff

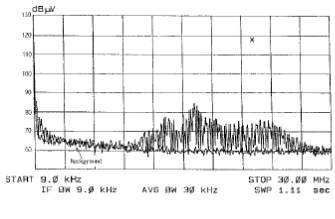
B2：合适的软开关技术

able 2

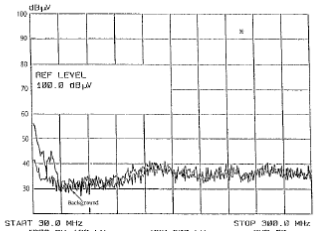
Curren

City University of Hong Kong

BUCK/BOOST/FLYBACK

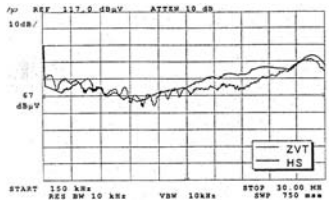


传导发射

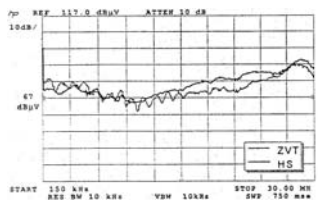


辐射发射

CPES Hard-switching vs. soft-switching of a inverter



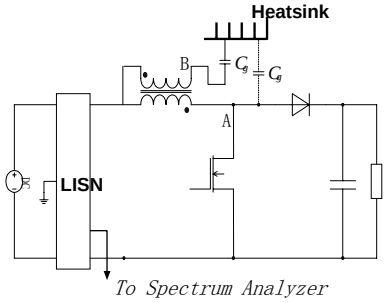
L 线传导发射

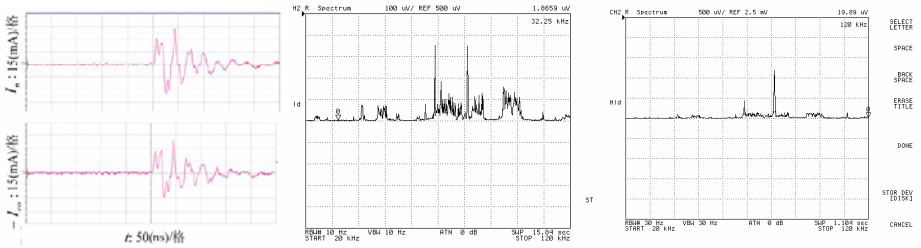


N 线传导发射

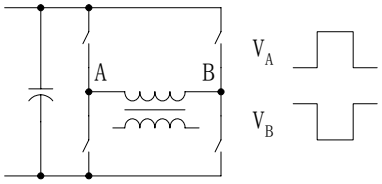
B3：反向补偿技术

Feedback Coil in the Boost Inductor





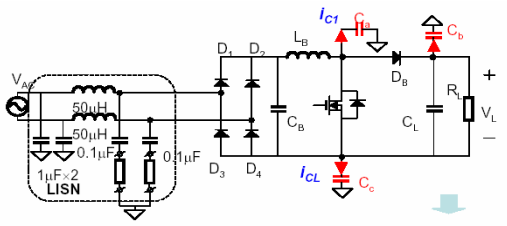
B4：对称平衡结构➔抑制共模发射的有效办法

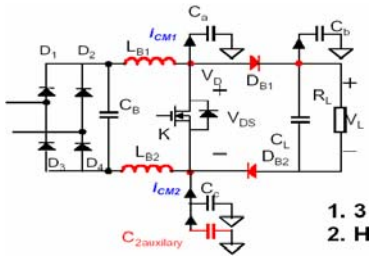


ZERO CM EMISSION!

FBSP bad CM emission!!

Symmetric trigger



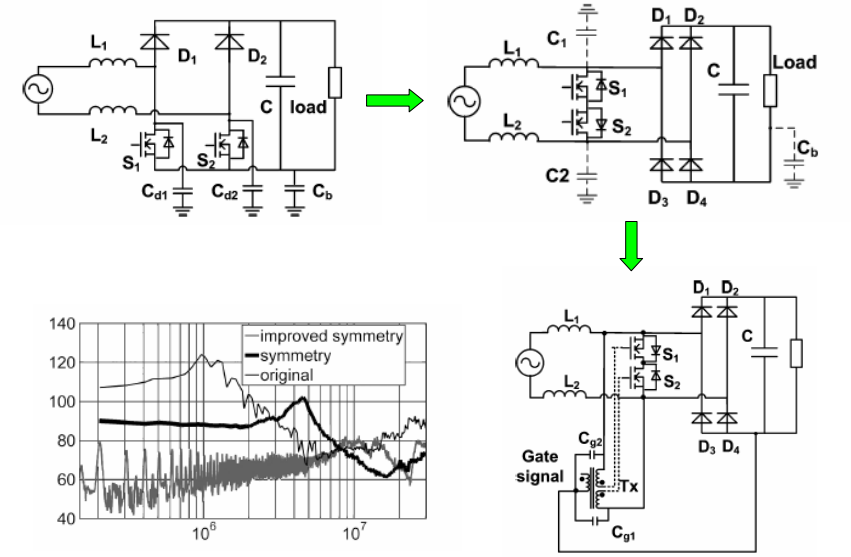


Symmetric structure

These principle has early been proposed in 90's and it can be used in any topology.

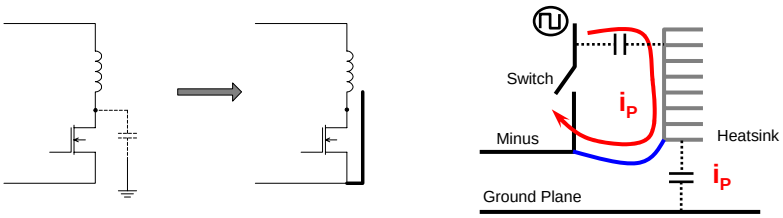
Low effectiveness, high cost!

Dual Boost：CM Emission is large.

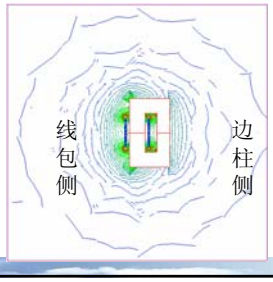


B5：巧用屏蔽

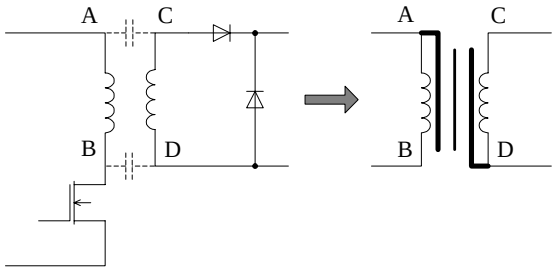
1. Heatsink Connected to the Minus bus



2 . Copper Foil around X'FORM

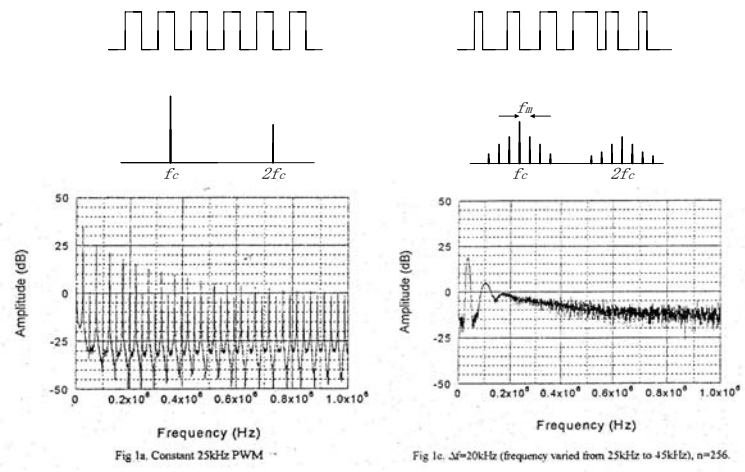


3: Shielding primary and secondary of transformer



Delta com：USA patent 20070171585
Method for suppressing common mode noise

B6：频率调制技术

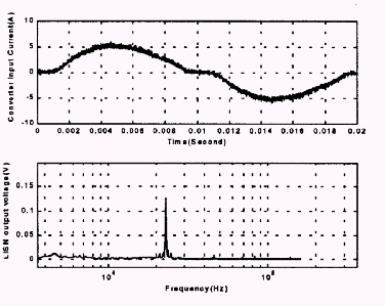


Switching frequency modulation
__ proposed by F. Lin et al , IEEE PESC'93

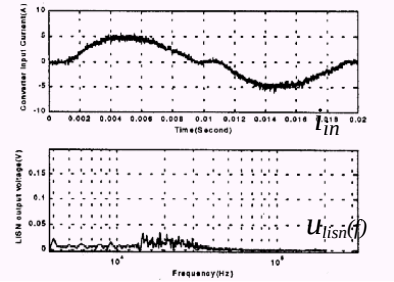
- ***Random modulation***
  _____ *proposed by D.A. Stone et al, IEEE APEC'96*

- ***Sigma - Delta modulation***
  _____ *proposed by J. Paramesh et al, IEEE APEC'99*

- ***Comparison : PWM & RPWM*** [43]



PWM, f = 25 kHz

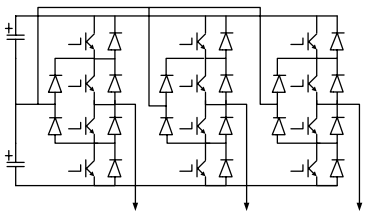


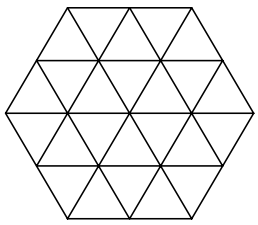
RPWM, 15 kHz< f <30 kHz

已商业化！

抖频幅度要大于10kHz. 输出直流有调制纹波！

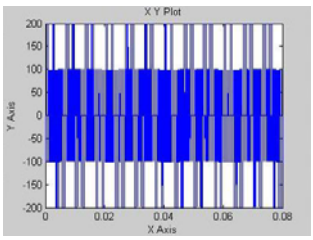
B7：合理触发控制

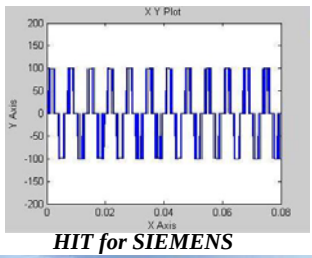




三电平逆变器共存在27状态， ***存在Ua+Ub+Uc小的SVPWM策略***

CM Voltage 可从Ubus/3 降到 Ubus/6 ！



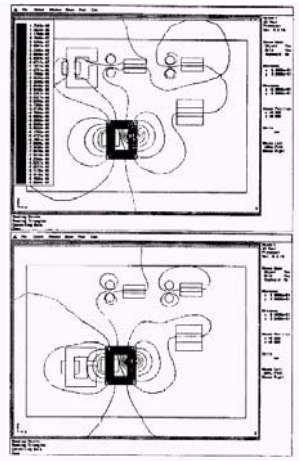


HIT for SIEMENS

B8：PCB精心设计

减小dv/dt导体面积，减小di/dt回路面积！
敏感电路远离高dv/dt、di/dt点！

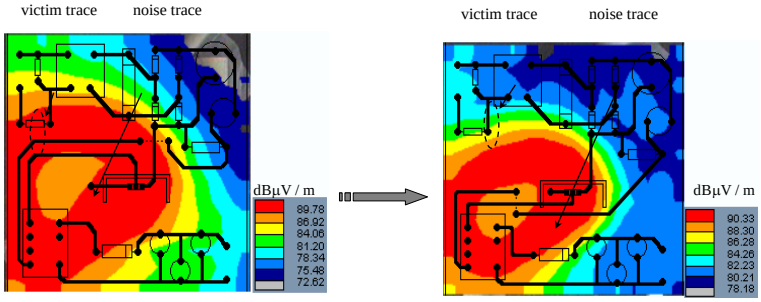
MAXWELL Software Assistant Method



(a) Flux plot of quasi-resonant boost converter with basic layout

(b) Flux plot of quasi-resonant converter with changed good layout

Routing Traces by Electrical Field Emission scan



___ *proposed by X. Wu Zhejiang Univ, IEEE APEC'99*

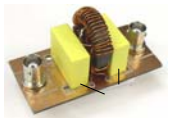
- The victim trace in weaker emission area is likely to pick up less noise;
- PCB designers can arrange critical trace in suitable position to receive less interference according to emission map.

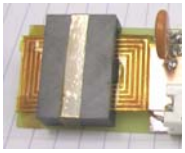
四.开关电源电磁兼容研究新进展

A：EMI滤波器的杂散耦合效应和集成化

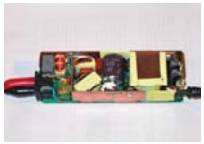
B：开关电源主电路近场耦合效应

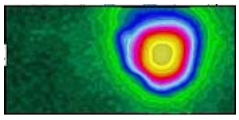
C：电源辐射机理研究





CPES

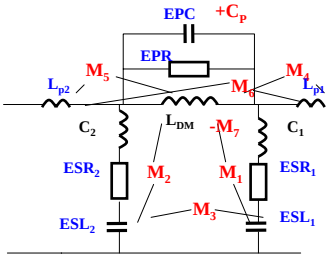




Tsinghua Univ/Delta Com

A：EMI滤波器的杂散耦合效应和集成化

VT CPES DM Filter



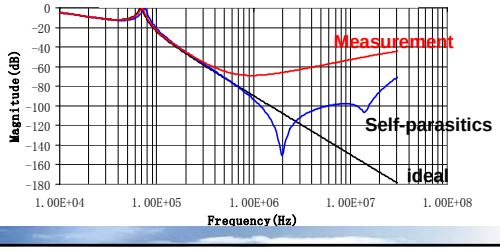
1) Couplings between L and C ; $M_{1,2}$

2) Couplings between L and trace loops; $M_{4,5}$

3) Couplings between capacitors; M_3

4) Effects of ground plane; C_P, M_7

Insertion Voltage Gain



五．结束语

开关电源电磁兼容性是一个挑战性的领域，其的产生、预测和改善是国内外产业界、学术界共同面临的紧迫问题和研究热点。

目前对其研究和改善已有了不少办法，但仍有相当多的问题有待分析和解决，需要产学研结合起来，继续推进。

Any questions?

谢谢大家！

Thanks for your attention!