

Contents

FOREWORD.....	12
ACKNOWLEDGEMENTS.....	13
UNITS.....	14
ABBREVIATIONS USED.....	14
CHAPTER 1. WHAT IS A POWER SUPPLY?.....	17
Basic power supply parameters.....	19
Output voltage.....	19
Output voltage tolerance.....	20
Output voltage regulation.....	20
Input regulation.....	20
Output ripple and noise.....	22
Transient load regulation.....	23
Efficiency.....	24
Power rating.....	25
Protection features.....	25
Safety rating.....	27
EMC.....	28
Does my power supply need regulation?.....	28
Linear v. switched-mode.....	29
CHAPTER 2. MAINS POWERED LINEAR POWER SUPPLIES.....	33
Transformers.....	33
How to specify the transformer.....	34
Primary voltage specification.....	34
Duty cycle rating.....	35
Why a transformer gets hot.....	36
How transformers are rated for power.....	37
Specifying the secondary winding parameters.....	37
Effective winding resistance.....	40
Testing a transformer.....	41
Rectifier selection.....	41
Different rectifier schemes and their effect on design.....	41
Rectifier fundamentals.....	42
Capacitor selection.....	45
Effect of ESR on ripple voltage.....	48
Selecting a suitable capacitor.....	48

Inrush-current limiting	49
Voltage doubler - high voltage power supplies	50
Mains input connectors	52
Fuses and fusing	53
Slow-blow fuse (anti-surge)	54
Medium speed fuses	55
Fast-acting fuses.....	56
Where to connect the fuse in the circuit	57
Fast electronic fuse	58
 CHAPTER 3. LINEAR REGULATOR CIRCUITS	 59
Shunt regulators	59
Series stabilisers	65
Basic series stabiliser	65
Increasing output current	67
Potential problems with the TO-3 package.....	69
Current sensing circuitry	71
Voltage feedback circuitry.....	73
Remote sensing	75
Metering voltage and current	77
Voltage metering.....	77
Current metering.....	78
Adding over-voltage protection	79
Testing OVP operation	81
Integrated circuit voltage regulators	82
Circuits using three-terminal linear regulators	84
High efficiency three-terminal regulators	88
Voltage regulators for automotive applications	91
<i>Low-drop out regulators in automotive</i>	93
 CHAPTER 4. SWITCHED-MODE POWER SUPPLIES	 94
How much better is a SMPS?	95
Origins of the switch mode supply	96
 CHAPTER 5. MAGNETICS BASICS	 98
Where does electromagnetism come from?	98
Back to earth	99
Coil inductance.....	100
Permeability	104
Flux Density	105

Air Gaps	110
Core losses	112
Transformers	114
Real inductors and transformers.....	115
'Dot notation'	117
Alternative core materials.....	118
Swinging chokes	118
Combinations, magnets	118
CHAPTER 6. NON-ISOLATED SWITCHED-MODE CONVERTERS.....	119
Charge pumps.....	119
Continuous and discontinuous mode.....	122
Hysteretic converters.....	123
Buck converters	128
Practical non-isolated buck converter circuits	129
Inductor selection	130
Output capacitor selection.....	133
Achieving even lower ripple voltage	134
Input capacitor selection.....	135
Selection of the recirculation diode	136
Multiple output buck converters	137
Disadvantages of the standard buck converter	138
Transient response characteristics.....	139
Synchronous buck converter.....	141
Some problems with the synchronous converter	144
Boost converter	147
Principle of operation.....	148
Design steps	149
Diode selection.....	152
Output capacitor selection.....	152
Input capacitor selection.....	153
Layout considerations for the LT1370.....	153
Multiple outputs with the boost converter.....	154
12V to 24V boost converter	154
The buck-boost converter.....	158
The SEPIC Converter	159
Basic calculations for example SEPIC	160
Synchronous SEPIC	163
Cuk converter	164
Zeta converter	165

Discrete non-isolated converter designs	166
CHAPTER 7. ISOLATED SWITCHED-MODE CONVERTERS	167
Flyback converters – fixed frequency.....	167
Why choose a flyback?	169
Single ended flyback.....	170
Power output	178
Diode ratings	178
Capacitor ratings	179
Transistor ratings.....	179
Snubber circuits.....	180
Voltage mode & current mode control	185
Self-oscillating flyback – variable frequency	187
Adding additional outputs.....	193
Isolated forward converters	195
Simple push pull converters – Royer.....	196
Single-ended forward converter	198
Two-switch forward converter.....	200
Active reset forward converter	202
Practical design – resonant reset forward converter.....	203
IC controlled push-pull	210
Half bridge converters.....	214
Full bridge converters	221
Current doublers	221
Multiple outputs from forward converters.....	223
Regulating secondary outputs from forward converters	224
Magnetic amplifiers.....	224
Resonant converters	228
Synchronous rectifiers in isolated converters	237
Forward converter synchronous rectification – IC controlled	237
Forward converter – self driven synchronous rectification	238
Flyback converter – synchronous rectification	239
CHAPTER 8. OFF – LINE CONVERTERS.....	240
Safety	240
Basic principles of electrical safety design	241
Working area	242
Hi-Pot testing.....	243
General arrangement of off-line converters	247
Mains filtering	248
Rectification	250
Reservoir (bulk) capacitor.....	251

Power factor correction	251
150W PFC stage	254
300W PFC stage.....	257
CHAPTER 9. OFF-LINE CONVERTER DESIGNS	259
A sniff of power	259
AC-DC PSU 30W, 5V / 6A, 88-264VAC	260
AC-DC PSU, 100W, +/-12V, +8A/-0.5A	264
CHAPTER 10. CONTROL LOOPS	269
Stability criteria	271
Other instabilities	272
Background - poles and zeros	273
Stabilising the Loop	280
Loop compensation example - buck converter, voltage mode control	284
Loop compensation example – isolated flyback converter, current mode control with optocoupler feedback	290
Measuring Gain and Phase margin	296
CHAPTER 11. EMC	297
Conducted noise	298
Radiated noise	298
Immunity	300
Screens and screening	300
CHAPTER 12. UC38XX SERIES	301
Operation of the UC384x series	302
Start-up voltages	303
Duty cycle selection	303
IC power considerations	304
Adjusting clock frequency	306
Power-up soft-start	307
Driving MOSFETs	309

Eliminating leading edge current spike	309
Voltage regulation	309
Other variants.....	309
CHAPTER 13. INTRODUCTION TO HIGH VOLTAGE SUPPLIES	310
Safety aspects.....	310
Connection between high voltage supply and amplifier	311
<i>Supply voltages required</i>	<i>313</i>
<i>Filament supply</i>	<i>315</i>
<i>Transformer requirements</i>	<i>315</i>
<i>On-off switching</i>	<i>316</i>
<i>Inrush current limiting</i>	<i>318</i>
<i>Mains transformer specification</i>	<i>320</i>
<i>Diode rating.....</i>	<i>321</i>
<i>Diode block stacks</i>	<i>321</i>
<i>Diode damping capacitors</i>	<i>322</i>
<i>Smoothing capacitor.....</i>	<i>322</i>
<i>Voltage sharing and bleeder resistors.....</i>	<i>324</i>
<i>Screen-grid stabiliser</i>	<i>328</i>
<i>Control grid stabiliser</i>	<i>329</i>
<i>Metering voltage and current.....</i>	<i>329</i>
<i>Control and protection circuitry</i>	<i>330</i>
<i>Primary transient protection.....</i>	<i>331</i>
<i>High voltage wiring</i>	<i>331</i>
<i>Input circuit breaker or fusing.....</i>	<i>332</i>
<i>Mains input connector</i>	<i>332</i>
CHAPTER 14. BATTERY BACKUP SUPPLIES	332
Discharge characteristics	333

Sealed lead-acid battery charging parameters	334
A more sophisticated charging method	336
Operation of the UC2906	337
A mast-head mounted battery supply	338
A high current battery shack supply.....	338
Principle of operation.....	339
Some words of caution on using car batteries	340
Solar powered battery backup supplies	342
Ni-Cd/Ni-Mh battery charger	343
Nickel-cadmium cell zapper	347
Nickel-cadmium cell rejuvenator	349
Lithium ion cells.....	351
Uninterruptible power supplies/inverters	352
 CHAPTER 15. CURRENT MONITORING AND SENSING	 353
Resistive sensing.....	354
Hall effect sensing.....	355
Current transformers.....	356
Burden resistor.....	357
Saturation.....	358
Bandwidth	359
Leakage inductance.....	359
Transformer reset	359
 CHAPTER 16. DESIGN FOR RELIABILITY/LIFETIME	 360
Derating.....	360
MTBF and lifetime	361
MTBF and MTTF.....	362
Reliability in use	362
 CHAPTER 17. HEATSINKING AND COOLING	 363
Thermal models.....	364
Calculating junction temperatures.....	364

Sizing heatsinks	366
Convection cooling	366
Fan cooling	367
Radiation cooling	368
CHAPTER 18. TRANSFORMER CONSTRUCTION TECHNIQUES	369
Starting point.....	369
Winding example margin tape	371
Winding example triple insulated wire (TIW).....	376
Foil windings.....	377
'Litz' or bundled windings.....	377
Split bobbins	377
CHAPTER 19. POWER SUPPLY TEST EQUIPMENT	378
What you need	378
DMM	378
Bench PSUs.....	378
Oscilloscope.....	379
Isolating transformer.....	380
Variat TM	380
Signal generator	381
AC current probe	381
Inductance meter	381
Resistive loads	382
Lamp loads	383
Electronic loads	383
Digital thermometers	386
Other equipment.....	386
Testing practice	386
Measuring output noise	386
Measuring input noise.....	387
Transient load response testing.....	389
Measuring efficiency	389
Measuring high currents	390
Testing high voltage transformers	392
CHAPTER 20. COMMISSIONING AND TROUBLESHOOTING CONVERTERS	394
New designs	394
Troubleshooting existing designs.....	397

Typical fault-finding problem	398
CHAPTER 21. PCB LAYOUT CONSIDERATIONS.....	403
Some tips on construction	405
CHAPTER 22. COMPONENT PARAMETERS.....	406
Resistors	406
Capacitors.....	407
Polyester.....	407
Ceramic	407
Polypropylene	408
Aluminium electrolytic	408
Tantalum	412
Speciality capacitors – OSCON.	413
Magnetics	413
Inductors	413
Transformers	415
Switching transistors	416
MOSFETs	416
Bipolar junction transistors (BJTs).....	419
Insulated Gate Bipolar Transistors (IGBTs).....	419
Diodes	420
Standard and fast recovery diodes.....	420
Schottky diodes	420
APPENDIX 1: GENERAL DESIGN EQUATIONS – CONTROL LOOPS.....	421
APPENDIX 2: POWER MAGNETICS DESIGN EQUATIONS.....	422