

Tube Amplifier Circuits

From SRPP and Mu-Follower
to OTL Designs



Peter Dieleman

● This is an Elektor Publication. Elektor is the media brand of
Elektor International Media B.V.
PO Box 11, NL-6114-ZG Susteren, The Netherlands
Phone: +31 46 4389444

● All rights reserved. No part of this book may be reproduced in any material form, including photocopying, or storing in any medium by electronic means and whether or not transiently or incidentally to some other use of this publication, without the written permission of the copyright holder except in accordance with the provisions of the Copyright Designs and Patents Act 1988 or under the terms of a licence issued by the Copyright Licensing Agency Ltd., 90 Tottenham Court Road, London, England W1P 9HE. Applications for the copyright holder's permission to reproduce any part of the publication should be addressed to the publishers.

● Declaration

The author and publisher have made every effort to ensure the accuracy of the information contained in this book. They do not assume, or hereby disclaim, any liability to any party for any loss or damage caused by errors or omissions in this book, whether such errors or omissions result from negligence, accident, or any other cause. The author expresses his sincere gratitude to Arrow Electronics and Trenz Electronic for granting permission to include various tables, figures, and program codes in this book.

● **ISBN 978-3-89576-733-3** Print
ISBN 978-3-89576-734-0 eBook
ISBN 978-3-89576-735-7 ePUB

● © Copyright 2026 Elektor International Media
www.elektor.com
Editor: Patrick Wielders
Printers: Ipskamp, Enschede, The Netherlands

Elektor is the world's leading source of essential technical information and electronics products for pro engineers, electronics designers, and the companies seeking to engage them. Each day, our international team develops and delivers high-quality content - via a variety of media channels (including magazines, video, digital media, and social media) in several languages - relating to electronics design and DIY electronics. www.elektormagazine.com

Contents

1	Conventions and notations.....	18
2	Prior knowledge	21
2.1	The $3/2$ power law.....	21
2.2	The characteristics of triodes and of pentodes.....	23
2.3	The tube's replacement model	26
2.4	Amplifications and impedances.....	27
2.5	Output impedance.....	28
2.6	Operation points of end triodes	29
2.7	Efficiency.....	30
2.7.1	The pentode in class A	31
2.7.2	The triode in class A	33
3	The constant μ	37
3.1	The ECC83.....	37
3.2	The PCF82	39
3.3	The ECC81	41
3.4	The 6SN7 and the 12SN7	42
3.5	The 12AY7	43
3.6	The rest of all triodes.....	44
4	Distortion	45
4.1	The first acquaintance	45
4.2	Combating the distortion	51
4.3	On the influence of the load line	52
4.3.1	Computing the influence of R_a/r_i	53
4.3.2	A computational example	54

5	Distortion and negative feedback.....	55
5.1	Amplification	55
5.2	Bandwidth	56
5.3	Distortion.....	56
5.3.1	The power series	57
5.4	The same effect in the resistance amplifier	60
5.5	Internal versus external feedback	62
6	The SRPP fundamentals	64
7	The SRPP mathematics	66
7.1	The symmetric SRPP	68
7.1.1	The output impedance.....	68
7.1.2	The dynamic transconductance	69
7.2	The asymmetric SRPP	69
7.2.1	The amplification.....	71
7.2.2	The asymmetric SRPP's output impedance	72
7.3	Comparing the symmetric and the asymmetric SRPP.....	74
7.4	Conclusions.....	74
8	The deceiving SRPP	75
8.1	The small distortion.....	77
8.1.1	A positive signal gives a larger current.....	79
8.1.2	A negative signal gives a lower current.....	79
8.2	The normal resistance amplifier.....	80
9	SRPP tubes elaborated.....	82
9.1	The ECC83 with $U_b = 500\text{ V}$	82
9.1.1	The positive grid signal.....	83
9.1.2	The negative grid signal.....	85

9.1.3	The distortion	85
9.1.4	The conclusion.....	86
9.1.5	The output impedance.....	87
9.2	The first interim result.....	87
9.2.1	The ECC83 with $U_b = 300$ V.....	87
9.2.2	The positive grid signal.....	89
9.2.3	The negative grid signal.....	89
9.2.4	The distortion	89
9.3	The second interim result.....	90
9.4	The ECC82 with $U_b = 540$ V	90
9.4.1	The positive grid signal.....	92
9.4.2	The negative grid signal.....	92
9.4.3	The distortion	92
9.5	The third interim result	92
9.6	The ECC81 with $U_b = 506$ V	93
9.6.1	The positive grid signal.....	94
9.6.2	The negative grid signal.....	94
9.6.3	The distortion	94
9.7	Fourth interim result	95
9.8	The ECC88.....	95
9.8.1	The positive grid signal.....	98
9.8.2	The negative grid signal.....	98
9.8.3	The distortion	98
9.9	The 12AY7 with $U_b = 508$ V	99
9.9.1	The positive grid signal.....	100
9.9.2	The negative grid signal.....	100

9.9.3	The distortion	100
9.10	The 6SN7 with $U_b = 492$ V	100
9.10.1	The positive grid signal	102
9.10.2	The negative grid signal	102
9.10.3	The distortion.....	102
9.11	The 6SN7 with $U_{ak} = 270$ V.....	103
9.11.1	The positive grid signal	104
9.11.2	The negative grid signal	104
9.11.3	The distortion.....	104
9.12	The ECC83 with an output of 240 V _{tt}	105
9.12.1	The positive grid signal	105
9.12.2	The negative grid signal	106
9.12.3	The distortion.....	106
9.13	The ECC99	106
9.13.1	The positive grid signal	111
9.13.2	The negative grid signal	111
9.13.3	The distortion.....	111
9.14	The 6FQ7 with $U_{ak} = 250$ V.....	112
9.14.1	The positive grid signal	113
9.14.2	The negative grid signal	113
9.14.3	The distortion.....	113
9.15	In summary	114
10	The Touzelet approach	115
10.1	The solution using matrix algebra	116
10.2	The elaboration step by step	118
11	The influence of differences in μ and p values	122

11.1	Different μ values	122
11.2	Different perveance values	127
12	Summary and conclusions	132
12.1	The circuit	132
12.2	The DC settings	132
12.3	The tubes choice.....	133
12.4	The perveance	136
12.4.1	The 6SN7 with a negative grid voltage of 8 V	136
12.5	The three triodes compared.....	138
12.6	The end conclusion.....	139
13	Introduction to Active Load amplifiers	141
13.1	A first attempt to elaborate this.....	143
14	The μ -follower.....	145
14.1	The principle	145
14.2	What are the improvements?	148
14.3	The setback.....	149
14.4	The choice of tube	149
15	The β -follower.....	152
15.1	The approach with a transistor	153
15.2	The approach using a FET	156
15.3	The tube's choice.....	158
15.4	The output impedance	159
16	The μ -amplifier with a pentode	160
16.1	The load is a pentode	160
16.2	The decoupling elcos	163
16.3	The setback.....	164

17	The μ -stage with a bootstrapped pentode	168
18	The semiconductor current source.....	170
18.1	Discussion of the schematic	171
19	OTLs or Output Transformer-Less end stages	174
19.1	The theoretical model	175
19.2	The schematic of the TV end stages	178
20	The Philips TV set 21CX172A.....	179
21	The two end stages of a Philips radio B7X63A.....	181
21.1	The end stage	182
21.2	The schematic.....	184
22	The Philips experimental amplifier HF303	187
22.1	The specifications	187
22.2	The design.....	188
22.3	The theory	189
22.3.1	The amplification	192
22.3.2	The distortion.....	193
22.4	Conclusion	194
22.5	Applying (22.12).....	194
22.6	Distortion by 3 th harmonics	195
22.7	Theoretical part. The Calculation of the distortions.....	196
22.7.1	For the 2 nd Harmonic.....	197
22.7.2	For the 3 rd harmonic	198
23	The 6C33C end stage.....	200
23.1	The cathode follower.....	202
23.2	The second variant	203
23.3	The Push-Pull variant.....	203

23.4	The Wheatstone Bridge	204
23.5	The Futterman variant.....	205
23.6	The Technics variant	207
23.7	The calculations on the Technics variant	208
23.8	Efficiency.....	210
23.9	Distortion	212
24	Power supply matters	214
24.1	The SRPP filament power supply	214
24.1.1	The first solution	215
24.1.2	The second solution	215
24.2	The glowing for the active-load stages.....	218
24.3	More than one winding to prevent damage	219
24.4	The high supply voltage	219
24.5	The Power Supply Rejection Ratio.....	222
25	The frequency characteristics	223
25.1	The Miller-effect	223
25.2	The AC resistance of active-load circuits.....	224
25.3	The SRPP	225
25.4	The active-load circuits	225
25.4.1	The first point.....	225
25.4.2	The second point	225
25.5	The low frequencies	226
26	The Cascode	228
26.1	A wrong cascode.....	230
27	The original SRPP patent with number 2,310,342	231
28	The White Cathode Follower	233

29	An unnecessary μ -follower	236
30	The Double SRPP or Bel Canto	239
30.1	The analysis	239
30.1.1	The left part	240
30.1.2	The right part	241
30.2	French Elektuur forum.....	242
30.3	Conclusion	243
30.4	Yet another exotic	244
31	Bad Design, Good Listening Test.....	245
32	OTL with an SRPP pre-stage.....	249
33	Danner's OTL.....	252
33.1	Conclusion	255
34	SRPP Phase Splitter	257
34.1	The first attempt with SRPPs	260
34.1.1	The symmetrical SRPP.....	261
34.1.2	The second attempt, an asymmetric SRPP	262
34.1.3	The last SRPP straw.....	262
34.1.4	The preliminary conclusion for the SRPP phase splitter..	262
34.2	The phase splitter combined with a mu-follower	263
34.3	The design through the open times approach	264
34.3.1	The circuit for the SRPP phase splitter.....	266
34.3.2	The final conclusion for the SRPP phase splitter	270
35	Power stage with real triodes 6BX7	271
35.1	The Counterfeit Triode	271
35.1.1	The principle	272
35.1.2	The Difference in Tone.....	274

35.1.3	The Comparison	275
35.2	Parallel Connection of Tubes	276
35.2.1	The counter-argument.....	278
35.3	NGV versus cathode decoupled resistance	280
35.4	The design.....	281
35.4.1	The end stage.....	283
35.4.2	The β -follower.....	284
35.4.3	The phase splitter	285
35.4.4	The negative supply voltage	286
35.4.5	The adjustable NGVs.....	286
35.4.6	The supply voltages	287
35.4.7	The filament power supply	288
35.4.8	Construction.....	289
36	The 6AS7 Amplifier with an SRPP	291
36.1	The Tube 6AS7	291
36.2	The output stage.....	293
36.2.1	The Setting	295
36.2.2	The end tube's cathode voltage	295
36.3	The SRPP Driver	297
36.4	The phase splitter	298
36.5	The Sound Control	299
36.6	The Input stage	300
36.7	The Power Supply	301
36.7.1	The High Voltage.....	302
36.7.2	The SRPP high voltage.....	304
36.7.3	The Filament Power Supply	305

36.7.4	The stabilizer	307
36.7.5	The Negative Power Supply	308
36.7.6	The NGVs.....	308
36.8	Trafo primary and fuses.....	309
36.9	Switch-on Phenomena.....	310
36.10	Negative feedback.....	311
36.11	Construction.....	312
36.11.1	Tube numbering.....	313
37	Appendix A Internet addresses.....	316
38	Appendix B Power Series and their Inverse	317
38.1	B.1 Some graphs to get into it	318
38.2	B.1.1 The drop-off frequency characteristic.....	318
38.3	B.1.2 The diode characteristic	319
38.4	B.2 The inverse of a function	320
38.5	B.2.1 The drawing of an inverse	321
38.6	B.2.2 The calculation of the inverse or 'reverse'	323
38.6.1	B.2.3 The convergence, or does the inverse exist?.....	326
39	Appendix C Tube theory.....	327
39.1	C.1 The simple model repeated	327
39.2	C.2 The extended model.....	328
39.3	C.3 Glow power and temperature	339
39.4	C.4 Historical developments in emission knowledge	341
39.5	C.4 Finally	344
40	Appendix D.....	345
	A graphical method to calculate the distortion	345
40.1	The calculation of the distortion by 2 nd harmonics	345

40.2	The calculation of the distortion by 3 ^e harmonics	348
41	Appendix E Cathode follower distortions	353
41.1	Computation of the distortions	355
41.1.1	ECC82	355
41.1.2	ECC83	356
41.1.3	ECC81	356
41.1.4	6SN7	356
41.2	Conclusions.....	357
42	Appendix F Myths	358
42.1	The different kangaroo impedances	358
42.2	The need for the SRPP cathode follower.....	360
43	References	364
44	Reflections	366

Preface

In 2004 Elektor published my first book:
'Theorie en Praktijk van Buizenversterkers'.

The book was a success and soon it was translated into French and into German.

'Théorie & pratique des amplificateurs audio à tubes' was the French title.
The German name was 'Theorie und Praxis des Röhrenverstärkers'.

I wrote the book because in those days knowledge on tubes was not easily available.

In a German Elektuur book 'Audio en HiFi-buizen', the author Rainer zur Linde described an SRPP driver invented by K. Anzai in 1969. I asked myself why such an SRPP would be better than a classic anode resistance amplifier.

I started doing calculations on the design.

It was wrong. I found out about the most infamous mistake (the cathode elco).

I got interested and later on I learned that the design had three of the errors mentioned in this SRPP book in it.

Although the design was wrong, the idea was inspiring. I did research and one of the designs in my first book had such an SRRP but now without the errors.

In the following years I did more research on SRPPs but also on mu-followers and OTLs.

In 2009 Elektor published my second book on these matters.
It was immediately translated into German.

Today Elektor and I still get requests for a reprint. The books are out of stock. Elektor decided no to do another reprint but instead to translate the book into English thus reaching a much larger readers community.

The result is this book. It has been revised a bit. The Dutch version contained a few little errors and my knowledge has grown in the past years.

I consider this version to be much better than the Dutch and the German ones.

It is consequent in style and much more accurate in the details.

I want to thank Jan Didden who inspired Elektor and me to accept the translation and the publishing job. I got in contact with him and he made me publish the article 'Myths in Tube Circuit Design' in the audioxpress magazine in May 2023.

I thank Menno van der Veen for his inspiring words and friendship during the past many years.

I thank Elektor's Patrick Wielders for having transformed the manuscript into a good looking book.

Introduction

Tube amplifiers suffer from distortion.

Fortunately, there exist SRPP amplifiers, μ -followers, β -followers etcetera.

All these produce a minimal distortion even with output voltages of 50 to 100 V_t.

Often these designs are published with errors in them.

It shows to be easy to make a wrong design when we do not have a good understanding of the theory.

In the first section of this book we investigate the origin of the distortion and after that the design of an SRPP and of a μ -follower.

On the internet we can find the most exotic designs. Evaluating them teaches us that these designs often make things worse than they are by nature. In the chapter on wrong SRPPs and μ -followers we sometimes see bizarre but also misplaced designs where a simple, one triode amplifier would perform much better.

There exist push-pull end stages. These are investigated and the similarity with the SRPP are looked at. This is done especially with the theory behind the OTL based on the 'mother' of all OTLs, the Philips HF303.

Finally attention is given to the frequency characteristics and technical matters like the supply voltage and the power supply of the filaments.

In order to illustrate things there are a few designs that describe the discussed subjects.

This book describes much new theory that has not been published before.

Often it is an eye opener as it shows that most things have a beautiful and unexpected simplicity.