EE4-18
EE9-AO6

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2018

MSc and EEE PART IV: MEng and ACGI

Corrected copy

RADIO FREQUENCY ELECTRONICS

Monday, 14 May 10:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer FOUR questions.

All questions carry equal marks

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible	First Marker(s) :	S. Lucyszyn
	Second Marker(s) :	W.T. Pike

Special instructions for invigilators

This is a closed book examination.

Special instructions for students

All variable have their usual meaning.

Standard filter curves and tables are given at the back.

The Questions

1.

a) The frequency spectrum has limits on performance and low cost exploitation.

i) As frequency decreases below 1 GHz, what affects the signal/noise ratio of a wireless communications system?

[2]

ii) Why is the frequency spectrum between 1 GHz and 10 GHz so convenient for commercial exploitation?

[2]

iii) Where in the frequency spectrum are the water and oxygen absorption peaks, between 10 GHz and 200 GHz?

[2]

iv) What is significant about the 38 GHz and 94 GHz frequency bands? Give an appropriate application for each band and state the reasons for choosing these applications.

[2]

v) What is significant about the 60 GHz frequency band? Give two applications for this band and state the reasons for choosing these applications.

[2]

b) Draw the block diagram for a TVRO LNB. For each block, comment on the suitability for their implementation using monolithic technology.

[10]

2.

a) An RF signal of 1 mW is input to a power amplifier with an output of 1 W. Design a suitable power amplifier configuration to give the best overall performance using the following transistor stages.

	$P_{OUT\|MAXLIN}$ [dBm]	P_{DC} [mW]	IP_3 [dBm]
Stage 1	25	600	40
Stage 2	30	2000	40
Stage 3	15	60	40

Table 2.1 Transistor Stage Specifications.

(Note that all the transistors have a perfect impedance matching)

[2]

b) From the design in 2(a), calculate the following at each stage and the overall values for:

i) Power gain [1]

ii) Output power [2]

iii) Basic efficiency [2]

iv) PAE [2]

v) IP_3 [2]

vi) IMD_3 for two-tone power level given in (ii) [2]

vii) Dissipated power [2]

c) From first principles, prove that the 3rd order intermodulation log-power gain slope is three times that of the desired output log-power slope.

[2]

d) In linear operation, if the overall input power drops by 3 dB, what happens to the following:

i) Output power [1]

ii) I_3 power [1]

iii) IMD_3 [1]

3.

a) The Michelson interferometer, shown in Figure 3.1, can be analysed as a general two-port network. By inspection of Figure 3.1, write down equations for the effective forward voltage-wave transmission coefficient S_{21} and input voltage-wave reflection coefficient S_{11} for this passive and reciprocal network. Clearly define all variables used. Hints, the electrical path lengths can be represented by $(k_o dx)$, where $k_o = 2\pi/\lambda$, λ is the wavelength for a monochromatic RF input signal source, integer x identifies a particular path and the beam splitter is both symmetrical and reciprocal.
[6]

b) Given that the optical path difference is given by $\delta = 2(d3 - d4)$, if $d1 = d2 = \lambda$ and both mirrors are made from perfectly conducting metals, simplify the equations obtained in 3(a).
[3]

c) For this interferometer to function properly, an ideal beam splitter must reflect 50% of any incident power and allow the rest of the power to be transmitted through without attenuation.

i) Write down the effective forward voltage-wave transmission and forward voltage-wave reflection coefficients for an ideal beam splitter, given that they must be in phase quadrature with one another. Hint, there are a number of possible solutions, so only choose one.
[4]

ii) From the solution obtained in 3(c)(i), show that the beam splitter obeys the conservation of energy principle.
[2]

iii) Using the solution obtained in 3(c)(i), simplify the equations obtained in 3(b).
[2]

iv) From the solution obtained in 3(c)(iii), show that this Michelson interferometer obeys the conservation of energy principle for $\delta = n\lambda$ and $(n+1/2)\lambda$, where n is any positive integer.
[3]

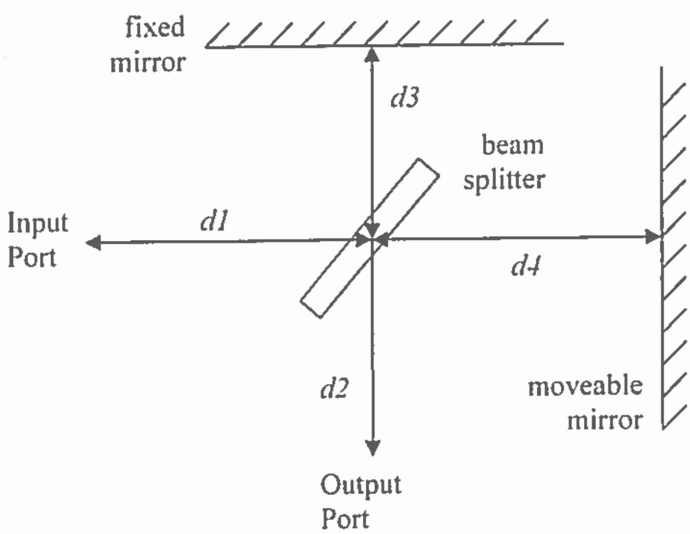


Figure 3.1 A Michelson interferometer

4.

a) Draw the topology of a double-balanced amplifier. If 3 dB quadrature couplers are used in conjunction with identical non-ideal single-ended amplifiers, use S-parameter analysis to determine expressions for the overall insertion gain and input return loss. Assume the couplers are perfectly matched to the reference impedance *Zo* and the interconnections between the main components are ideal.

[10]

b) For the topology in 4(a), if the working single-ended amplifiers have a forward voltage wave transmission coefficient of $S_{21} = |10|\angle 35°$, determine the overall insertion gain and input return loss if one of the amplifiers fails, such that $S_{21} = 0$. Assume that there is no change to the input or output impedances of the failed transistor. What is the main application of this topology and what are its advantages and disadvantages when compared to a single-ended amplifier?

[10]

5. The photograph in Figure 5.1 is of a MMIC.

a) Draw the basic equivalent circuit model for the MMIC shown in Figure 5.1, and mark the RF and DC bias ports with the corresponding probe pad numbers shown. Describe the type of amplifier circuit. Hint: if you are uncertain about a component then state any assumptions used.

[10]

b) Briefly describe the different range of component technologies used for the transistors, inductors and capacitors, and also state the advantages and disadvantages of these technologies. State what compromises have to be made with the design of MMICs, when compared to HMICs.

[5]

c) Briefly comment as to why the complexity of the full equivalent circuit model is much more than the circuit derived in 5(a) and explain why circuit modelling alone is not sufficient if a significant reduction in the chip area is required.

[5]

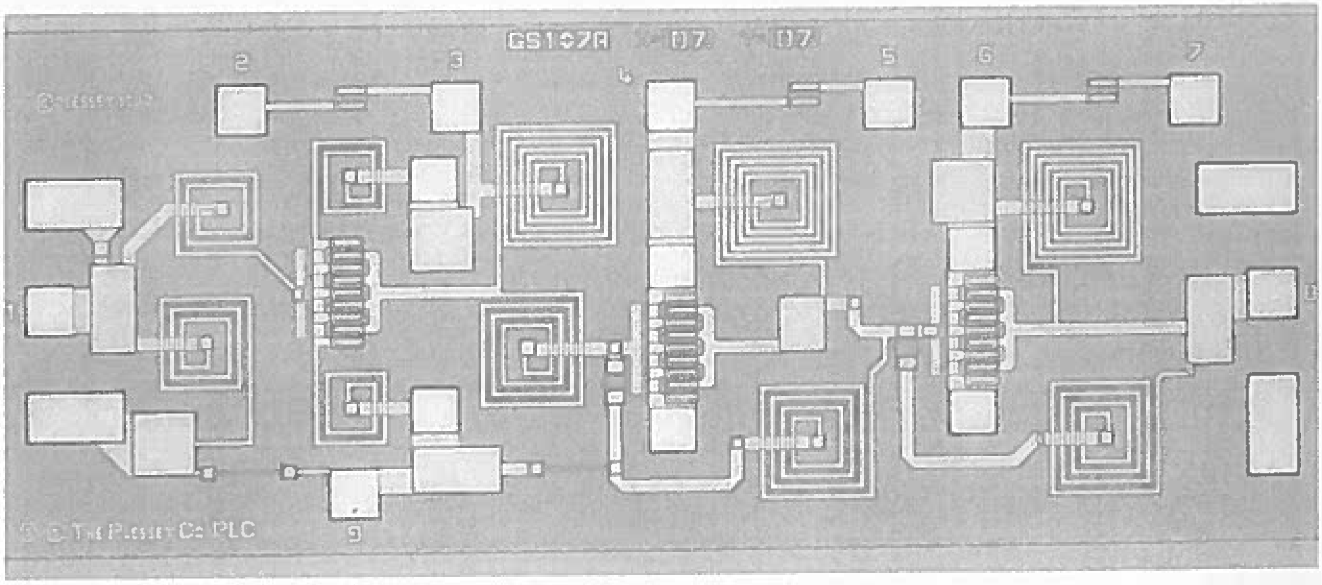


Figure 5.1 Photograph of a 3.5 x 1.5 mm^2 LNA

6.

a) With the use of simple illustrations for the attenuation against frequency curves, describe the differences between Butterworth, Chebyshev and Elliptical-function filters. Also, comment on the group delay characteristics for these filters.

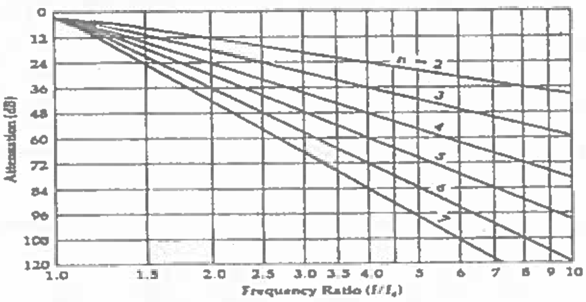
[5]

b) Given prototype low-pass filter attenuation curves and tables for the corresponding normalised element values (see attached sheets), design an L-C lumped-element band-pass filter that meets the following specifications:

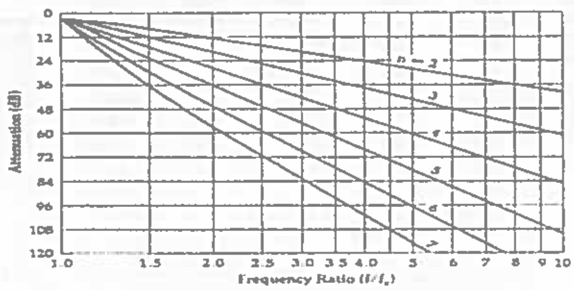
Centre Frequency, f_o	500 MHz
3 dB Bandwidth, B	50 MHz
Attenuation Bandwidth	100 MHz
Pass-Band Ripple (Peak-to-Peak)	0.1 dB
Stop-Band Attenuation	45 dB
Input Impedance, R_{IN}	100 Ω
Output Impedance, R_{OUT}	50 Ω

[15]

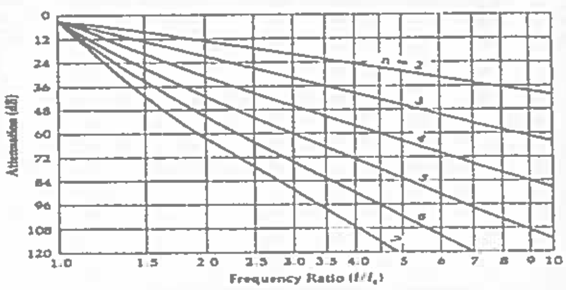
Standard Filter Curves and Tables



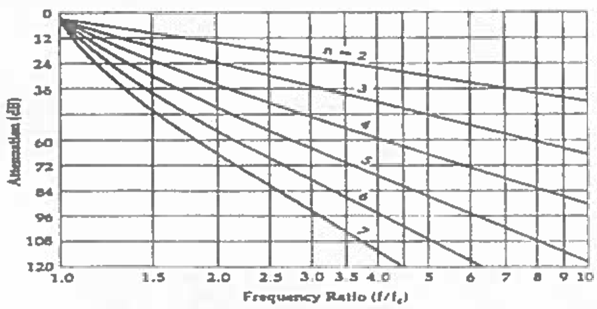
Attenuation characteristics for Butterworth filters.



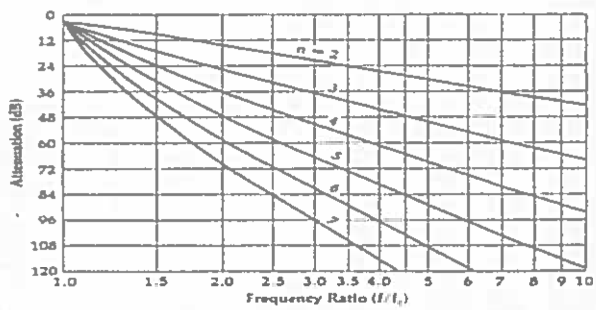
Attenuation characteristics for a Chebyshev filter with 0.01-dB ripple.



Attenuation characteristics for a Chebyshev filter with 0.1-dB ripple.

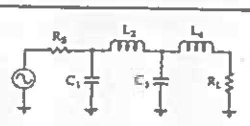


Attenuation characteristics for a Chebyshev filter with 0.5-dB ripple.

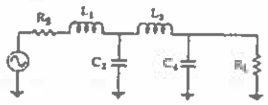


Attenuation characteristics for a Chebyshev filter with 1-dB ripple.

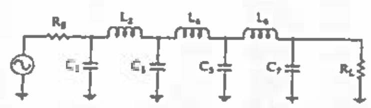
Chebyshev Low-Pass Prototype Element Values for 1.0-dB Ripple



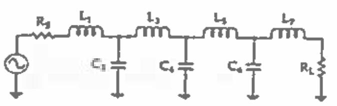
R_S/R_L	C_1	L_2	C_3	L_4
3.000	0.572	3.132		
4.000	0.365	4.600		
8.000	0.157	9.658		
∞	1.213	1.109		
1.000	2.216	1.088	2.216	
0.500	4.431	0.817	2.216	
0.333	6.647	0.728	2.216	
0.250	8.862	0.680	2.216	
0.125	17.725	0.612	2.216	
∞	1.652	1.460	1.108	
3.000	0.653	4.411	0.814	2.535
4.000	0.452	7.083	0.612	2.848
8.000	0.209	17.164	0.428	3.281
∞	1.350	2.010	1.488	1.106
R_L/R_S	L_1	C_2	L_3	C_4



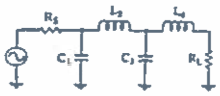
Chebyshev Low-Pass Prototype Element Values for 1.0-dB Ripple



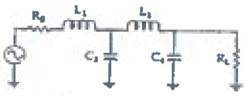
n	R_S/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	1.000	2.207	1.128	3.103	1.128	2.207		
	0.500	4.414	0.565	4.653	1.128	2.207		
	0.333	6.622	0.376	6.205	1.128	2.207		
	0.250	8.829	0.282	7.756	1.128	2.207		
	0.125	17.657	0.141	13.961	1.128	2.207		
	∞	1.721	1.645	2.061	1.493	1.103		
6	3.000	0.679	3.873	0.771	4.711	0.969	2.406	
	4.000	0.481	5.644	0.476	7.351	0.849	2.582	
	8.000	0.227	12.310	0.198	16.740	0.726	2.800	
	∞	1.378	2.097	1.690	2.074	1.494	1.102	
7	1.000	2.204	1.131	3.147	1.194	3.147	1.131	2.204
	0.500	4.408	0.566	6.293	0.895	3.147	1.131	2.204
	0.333	6.612	0.377	9.441	0.798	3.147	1.131	2.204
	0.250	8.815	0.283	12.588	0.747	3.147	1.131	2.204
	0.125	17.631	0.141	25.173	0.671	3.147	1.131	2.204
	∞	1.741	1.677	2.155	1.703	2.079	1.494	1.102
n	R_L/R_S	L_1	C_2	L_3	C_4	L_5	C_6	L_7



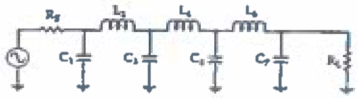
Butterworth Low-Pass Prototype Element Values



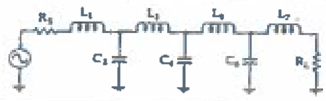
n	R_S/R_L	C_1	L_2	C_3	L_4
2	1.111	1.035	1.835		
	1.250	0.849	2.121		
	1.429	0.697	2.439		
	1.667	0.566	2.828		
	2.000	0.448	3.346		
	2.500	0.342	4.095		
	3.333	0.245	5.313		
	5.000	0.156	7.707		
	10.000	0.074	14.814		
	∞	1.414	0.707		
3	0.900	0.808	1.633	1.599	
	0.800	0.844	1.384	1.926	
	0.700	0.915	1.165	2.277	
	0.600	1.023	0.965	2.702	
	0.500	1.181	0.779	3.261	
	0.400	1.425	0.604	4.064	
	0.300	1.838	0.440	5.363	
	0.200	2.669	0.284	7.910	
	0.100	5.167	0.139	15.455	
	∞	1.500	1.333	0.500	
4	1.111	0.466	1.592	1.744	1.469
	1.250	0.388	1.695	1.511	1.811
	1.429	0.325	1.862	1.291	2.175
	1.667	0.269	2.103	1.082	2.613
	2.000	0.218	2.452	0.883	3.187
	2.500	0.169	2.986	0.691	4.009
	3.333	0.124	3.883	0.507	5.338
	5.000	0.080	5.684	0.331	7.940
	10.000	0.039	11.094	0.162	15.642
	∞	1.531	1.577	1.082	0.383
n	R_L/R_S	L_1	C_2	L_3	C_4



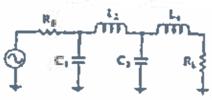
Butterworth Low-Pass Prototype Element Values



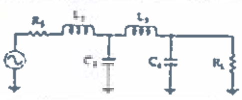
n	R_S/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	0.900	0.442	1.027	1.910	1.756	1.389		
	0.800	0.470	0.866	2.061	1.544	1.738		
	0.700	0.517	0.731	2.285	1.333	2.108		
	0.600	0.586	0.609	2.600	1.126	2.552		
	0.500	0.686	0.496	3.051	0.924	3.133		
	0.400	0.838	0.388	3.736	0.727	3.965		
	0.300	1.094	0.285	4.884	0.537	5.307		
	0.200	1.608	0.186	7.185	0.352	7.935		
	0.100	3.512	0.091	14.095	0.173	15.710		
	∞	1.545	1.694	1.382	0.894	0.309		
6	1.111	0.289	1.040	1.322	2.054	1.744	1.335	
	1.250	0.245	1.116	1.126	2.239	1.550	1.688	
	1.429	0.207	1.236	0.957	2.499	1.346	2.063	
	1.667	0.173	1.407	0.801	2.858	1.143	2.500	
	2.000	0.141	1.653	0.654	3.369	0.942	3.094	
	2.500	0.111	2.028	0.514	4.141	0.745	3.931	
	3.333	0.082	2.656	0.379	5.433	0.552	5.280	
	5.000	0.054	3.917	0.248	8.020	0.363	7.922	
	10.000	0.026	7.705	0.122	15.786	0.179	15.738	
	∞	1.553	1.759	1.553	1.202	0.758	0.259	
7	0.900	0.299	0.711	1.404	1.459	2.125	1.727	1.296
	0.800	0.322	0.606	1.517	1.278	2.334	1.546	1.652
	0.700	0.357	0.515	1.688	1.091	2.618	1.350	2.028
	0.600	0.408	0.432	1.928	0.917	3.005	1.150	2.477
	0.500	0.480	0.354	2.273	0.751	3.553	0.951	3.064
	0.400	0.590	0.278	2.796	0.592	4.380	0.754	3.904
	0.300	0.775	0.206	3.671	0.437	5.761	0.560	5.258
	0.200	1.145	0.135	5.427	0.287	8.526	0.369	7.908
	0.100	2.257	0.067	10.700	0.143	16.822	0.182	15.748
	∞	1.558	1.799	1.659	1.397	1.055	0.656	0.223
n	R_L/R_S	L_1	C_2	L_3	C_4	L_5	C_6	L_7



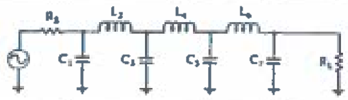
Chebyshev Low-Pass Element Values for 0.01-dB Ripple



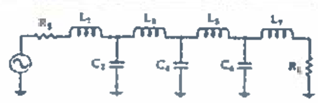
n	R_S/R_L	C_1	L_2	C_3	L_4
2	1.101	1.347	1.483		
	1.111	1.247	1.595		
	1.250	0.943	1.997		
	1.429	0.759	2.344		
	1.667	0.609	2.750		
	2.000	0.479	3.277		
	2.500	0.363	4.033		
	3.333	0.259	5.255		
	5.000	0.164	7.650		
	10.000	0.078	14.749		
	∞	1.412	0.742		
3	1.000	1.181	1.821	1.181	
	0.900	1.092	1.660	1.480	
	0.800	1.097	1.443	1.806	
	0.700	1.160	1.228	2.165	
	0.600	1.274	1.024	2.598	
	0.500	1.452	0.829	3.164	
	0.400	1.734	0.645	3.974	
	0.300	2.216	0.470	5.280	
	0.200	3.193	0.305	7.834	
	0.100	6.141	0.148	15.390	
	∞	1.501	1.433	0.591	
4	1.100	0.950	1.938	1.761	1.046
	1.111	0.854	1.946	1.744	1.165
	1.250	0.618	2.075	1.542	1.617
	1.429	0.495	2.279	1.331	2.008
	1.667	0.398	2.571	1.128	2.461
	2.000	0.316	2.994	0.920	3.045
	2.500	0.242	3.641	0.729	3.875
	3.333	0.174	4.727	0.538	5.209
	5.000	0.112	6.910	0.352	7.813
	10.000	0.054	13.409	0.173	15.510
	∞	1.529	1.691	1.312	0.523
n	R_L/R_S	L_1	C_2	L_3	C_4



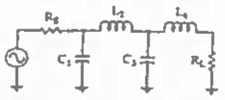
Chebyshev Low-Pass Element Values for 0.01-dB Ripple



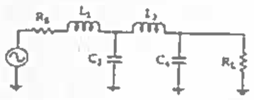
n	R_S/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	1.000	0.977	1.685	2.037	1.685	0.977		
	0.900	0.880	1.456	2.174	1.641	1.274		
	0.800	0.877	1.235	2.379	1.499	1.607		
	0.700	0.926	1.040	2.658	1.323	1.977		
	0.600	1.019	0.863	3.041	1.135	2.424		
	0.500	1.166	0.699	3.584	0.942	3.009		
	0.400	1.398	0.544	4.403	0.749	3.845		
	0.300	1.797	0.398	5.772	0.557	5.193		
	0.200	2.604	0.259	8.514	0.368	7.826		
	0.100	5.041	0.127	16.741	0.182	15.613		
	∞	1.547	1.795	1.645	1.237	0.488		
6	1.101	0.851	1.796	1.841	2.027	1.631	0.937	
	1.111	0.760	1.782	1.775	2.094	1.638	1.053	
	1.250	0.545	1.864	1.489	2.403	1.507	1.504	
	1.429	0.436	2.038	1.266	2.735	1.332	1.899	
	1.667	0.351	2.298	1.061	3.167	1.145	2.357	
	2.000	0.279	2.678	0.867	3.768	0.954	2.948	
	2.500	0.214	3.261	0.682	4.667	0.761	3.790	
	3.333	0.155	4.245	0.503	6.163	0.568	5.143	
	5.000	0.100	6.223	0.330	9.151	0.376	7.785	
	10.000	0.048	12.171	0.162	18.105	0.187	15.595	
	∞	1.551	1.847	1.790	1.598	1.190	0.469	
7	1.000	0.913	1.595	2.002	1.870	2.002	1.595	0.913
	0.900	0.816	1.362	2.089	1.722	2.202	1.581	1.206
	0.800	0.811	1.150	2.262	1.525	2.465	1.464	1.538
	0.700	0.857	0.967	2.516	1.323	2.802	1.307	1.910
	0.600	0.943	0.803	2.872	1.124	3.250	1.131	2.359
	0.500	1.080	0.650	3.382	0.928	3.875	0.947	2.948
	0.400	1.297	0.507	4.156	0.735	4.812	0.758	3.790
	0.300	1.669	0.372	5.454	0.548	6.370	0.568	5.148
	0.200	2.242	0.242	8.057	0.360	9.484	0.378	7.802
	0.100	4.701	0.119	15.872	0.178	18.818	0.188	15.652
	∞	1.350	1.867	1.866	1.765	1.563	1.161	0.456
n	R_L/R_S	L_1	C_2	L_3	C_4	L_5	C_6	L_7



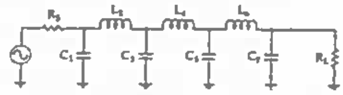
Chebyshev Low-Pass Prototype Element Values for 0.1-dB Ripple



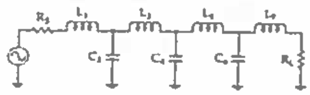
n	R_s/R_L	C_1	L_2	C_3	L_4
2	1.355	1.209	1.638		
	1.429	0.977	1.982		
	1.667	0.733	2.489		
	2.000	0.560	3.054		
	2.500	0.417	3.827		
	3.333	0.293	5.050		
	5.000	0.184	7.426		
	10.000	0.087	14.433		
	∞	1.391	0.819		
3	1.000	1.433	1.594	1.433	
	0.900	1.426	1.494	1.622	
	0.800	1.451	1.356	1.871	
	0.700	1.521	1.193	2.190	
	0.600	1.648	1.017	2.603	
	0.500	1.853	0.838	3.159	
	0.400	2.186	0.660	3.968	
	0.300	2.783	0.486	5.279	
	0.200	3.942	0.317	7.850	
	0.100	7.512	0.155	15.466	
	∞	1.513	1.510	0.716	
4	1.355	0.992	2.148	1.585	1.341
	1.429	0.779	2.348	1.429	1.700
	1.667	0.576	2.730	1.185	2.243
	2.000	0.440	3.227	0.967	2.856
	2.500	0.329	3.961	0.760	3.698
	3.333	0.233	5.178	0.560	5.030
	5.000	0.148	7.607	0.367	7.614
	10.000	0.070	14.887	0.180	15.230
	∞	1.511	1.768	1.455	0.673
n	R_L/R_s	L_1	C_2	L_3	C_4



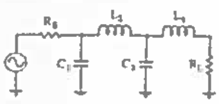
Chebyshev Low-Pass Prototype Element Values for 0.1-dB Ripple



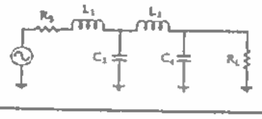
n	R_s/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	1.000	1.301	1.556	2.241	1.556	1.301		
	0.900	1.285	1.433	2.380	1.488	1.488		
	0.800	1.300	1.282	2.582	1.382	1.738		
	0.700	1.358	1.117	2.868	1.244	2.062		
	0.600	1.470	0.947	3.269	1.085	2.484		
	0.500	1.654	0.778	3.845	0.913	3.053		
	0.400	1.954	0.612	4.720	0.733	3.866		
	0.300	2.477	0.451	6.196	0.550	5.237		
	0.200	3.546	0.295	9.127	0.366	7.889		
	0.100	6.787	0.115	17.957	0.182	15.743		
	∞	1.561	1.807	1.766	1.417	0.651		
6	1.355	0.942	2.080	1.659	2.247	1.534	1.277	
	1.429	0.735	2.249	1.454	2.544	1.405	1.629	
	1.667	0.542	2.600	1.183	3.064	1.185	2.174	
	2.000	0.414	3.068	0.958	3.712	0.979	2.794	
	2.500	0.310	3.765	0.749	4.651	0.778	3.643	
	3.333	0.220	4.927	0.551	6.195	0.580	4.996	
	5.000	0.139	7.250	0.361	9.261	0.384	7.618	
	10.000	0.067	14.220	0.178	18.427	0.190	15.350	
	∞	1.534	1.884	1.831	1.749	1.394	0.638	
7	1.000	1.262	1.520	2.239	1.680	2.239	1.520	1.262
	0.900	1.242	1.395	2.361	1.578	2.397	1.459	1.447
	0.800	1.255	1.245	2.548	1.443	2.624	1.362	1.697
	0.700	1.310	1.083	2.819	1.283	2.942	1.233	2.021
	0.600	1.417	0.917	3.205	1.209	3.384	1.081	2.444
	0.500	1.595	0.753	3.764	0.928	4.015	0.914	3.018
	0.400	1.885	0.593	4.618	0.742	4.970	0.738	3.855
	0.300	2.392	0.437	6.054	0.556	6.569	0.557	5.217
	0.200	3.428	0.286	8.937	0.369	9.770	0.372	7.890
	0.100	6.570	0.141	17.603	0.184	19.376	0.186	15.813
	∞	1.575	1.858	1.921	1.827	1.734	1.379	0.631
n	R_L/R_s	L_1	C_2	L_3	C_4	L_5	C_6	L_7



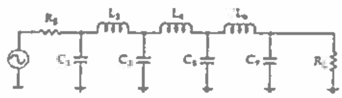
Chebyshev Low-Pass Prototype Element Values for 0.5-dB Ripple



n	R_s/R_L	C_1	L_2	C_3	L_4
2	1.984	0.983	1.950		
	2.000	0.909	2.103		
	2.500	0.564	3.165		
	3.333	0.375	4.411		
	5.000	0.228	6.700		
	10.000	0.105	13.322		
	∞	1.307	0.975		
3	1.000	1.864	1.280	1.834	
	0.900	1.918	1.209	2.026	
	0.800	1.997	1.120	2.237	
	0.700	2.114	1.015	2.517	
	0.500	2.557	0.759	3.436	
	0.400	2.985	0.615	4.242	
	0.300	3.729	0.463	5.576	
	0.200	5.254	0.309	8.225	
	0.100	9.890	0.153	16.118	
	∞	1.572	1.518	0.932	
4	1.984	0.920	2.586	1.304	1.826
	2.000	0.845	2.720	1.238	1.985
	2.500	0.516	3.766	0.880	3.121
	3.333	0.344	5.120	0.621	4.450
	5.000	0.210	7.708	0.400	6.987
	10.000	0.096	15.352	0.194	14.262
	∞	1.436	1.889	1.521	0.913
n	R_L/R_s	L_1	C_2	L_3	C_4



Chebyshev Low-Pass Prototype Element Values for 0.5-dB Ripple



n	R_s/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	1.000	1.807	1.303	2.691	1.303	1.807		
	0.900	1.854	1.222	2.849	1.238	1.970		
	0.800	1.926	1.126	3.060	1.157	2.185		
	0.700	2.035	1.015	3.353	1.058	2.470		
	0.600	2.200	0.890	3.765	0.942	2.861		
	0.500	2.457	0.754	4.367	0.810	3.414		
	0.400	2.870	0.609	5.296	0.664	4.245		
	0.300	3.588	0.459	6.871	0.508	5.625		
	0.200	5.064	0.306	10.054	0.343	8.367		
	0.100	9.556	0.153	19.647	0.173	16.574		
	∞	1.630	1.740	1.922	1.514	0.903		
6	1.984	0.905	2.577	1.368	2.713	1.299	1.796	
	2.000	0.830	2.704	1.291	2.872	1.237	1.956	
	2.500	0.506	3.722	0.890	4.109	0.881	3.103	
	3.333	0.337	5.055	0.632	5.699	0.635	4.451	
	5.000	0.206	7.615	0.406	8.732	0.412	7.031	
	10.000	0.096	15.186	0.197	17.681	0.202	14.433	
7	1.000	1.790	1.296	2.718	1.385	2.718	1.296	1.790
	0.900	1.835	1.215	2.869	1.308	2.883	1.234	1.953
	0.800	1.905	1.118	3.076	1.215	3.107	1.153	2.168
	0.700	2.011	1.007	3.364	1.105	3.416	1.058	2.455
	0.600	2.174	0.882	3.772	0.979	3.852	0.914	2.848
	0.500	2.428	0.747	4.370	0.838	2.289	0.814	3.405
	0.400	2.835	0.604	5.295	0.685	5.470	0.669	4.243
	0.300	3.546	0.455	6.867	0.522	7.134	0.513	5.635
	0.200	5.007	0.303	10.049	0.352	10.496	0.348	8.404
	0.100	9.456	0.151	19.649	0.178	20.631	0.176	16.665
	∞	1.648	1.777	2.031	1.789	1.924	1.503	0.895
n	R_L/R_s	L_1	C_2	L_3	C_4	L_5	C_6	L_7