

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2003

MSc and EEE PART IV: M.Eng. and ACGI

RADIO FREQUENCY ELECTRONICS

Wednesday, 7 May 10:00 am

Time allowed: 3:00 hours

There are SIX questions on this paper.

Answer FOUR questions.

Corrected Copy

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

Examiners responsible First Marker(s) : S. Lucyszyn
 Second Marker(s) : C. Papavassiliou

Special Information for Invigilators: none.

Information for Candidates: Filter tables and filter curves will be supplied

The Questions

1. A lossless coaxial cable has a distributed capacitance of 50 pF/m and distributed inductance of 280 nH/m.
 - (a) At an operational frequency of 1.8 GHz, calculate the following transmission line parameters:
 - (i) Characteristic impedance [1]
 - (ii) Propagation constant [2]
 - (iii) Guided wavelength [2]
 - (iv) Phase velocity [2]
 - (b) Given the electric and magnetic field intensities between the inner and outer conductors, show that the power flux density at the surface of a conductor is equal to the surface power density given in terms of the surface current and impedance variables. Illustrate all the vector variables. [6]
 - (c) For the coaxial cable in 1(a), if the electric field intensity between the conductors is 1 V/m and the conductors are made from copper (having a bulk DC conductivity of $\sigma_o = 5.8 \times 10^7$ S/m), determine the following surface parameters at 1.8 GHz ($\mu_o = 4\pi \times 10^{-7}$ S/m):
 - (i) Surface current density [2]
 - (ii) Surface impedance [3]
 - (iii) Surface power density [2]
2. A short transmission line is used to transform an arbitrary termination impedance, $Z = R + jX$, to the reference impedance, Z_o . The impedance looking into the transformer is given by the following expression:

$$z_{in} = \frac{z + jz_{TX} \tan \theta}{z_{TX} + jz \tan \theta} \quad (2.1)$$

the normalised variables used have their usual meanings

- (a) Using equation (2.1), derive the equations for the characteristic impedance of the transmission line, Z_{TX} , and the corresponding electrical length, θ . [10]
- (b) From the expressions derived in 2(a), what are the mathematical limits for the resistive and reactive values of the termination impedance that can be mapped into the input impedance of the short transmission line transformer? [3]
- (c) A load termination consisting of a 20 pF capacitance in series with a 2 Ω resistance must be matched at 900 MHz to a 50 Ω reference impedance using a short transmission line transformer. Using expressions derived in 2(a) and 2(b), calculate Z_{TX} and θ for the short transmission line transformer. [5]
- (d) Comment on the suitability, or otherwise, of implementing the short transmission line transformer calculated in 2(c) using conventional microstrip and thin-film microstrip technologies. [2]

3.

- (a) What are the levels of insertion loss and return loss at the -3 dB cut-off frequency for a lossless filter? You are asked to design a filter with a maximum pass band return loss level of -6.868 dB. What will be the worst-case pass band insertion loss ripple for a lossless filter?

[5]

- (b) Using the worst-case pass band insertion loss level calculated in 3(a), design a lumped-element L-C band stop filter to meet the following specifications:

Lower pass band -3 dB cut-off frequency:	540 MHz
Upper pass band -3 dB cut-off frequency:	660 MHz
Stop band bandwidth:	60 MHz
Band stop attenuation:	> 45 dB
Source impedance, Z_s :	50 Ω
Load impedance, Z_L :	100 Ω

[10]

- (c) Define group delay and explain the general relationship between its frequency response and that of sharp cut-off insertion loss characteristics.

[5]

4.

- (a) Using a signal flow graph or otherwise, derive an expression for the input voltage wave reflection coefficient for a 2-port network that is terminated with a load impedance Z_L .

[5]

- (b) From the expression derived in 4(a), describe how stability circles can be created on the Smith chart. What does this stability circle represent when it encompasses the impedance matched, z_o , point on the Smith chart and when it does not encompass this point?

[5]

- (c) Given a 2-port network with the following S-parameters:

$$[S] = \begin{bmatrix} 0.5 & 0.5 \\ 10 & 0.5 \end{bmatrix} \quad (4.1)$$

What is the input voltage wave reflection coefficient if the output port is terminated with a load impedance $Z_L = -5 \Omega$ and a reference impedance $Z_o = 50 \Omega$?

[5]

- (d) For the 2-port network given in 4(c) the Rollett's stability factor is 2.3. Comment on the apparent contradiction between the Rollett's stability factor and the input voltage wave reflection coefficient found in 4(c). What is the maximum gain that can be achieved with a passive load impedance termination?

[5]

5. Draw the topology of a double-balanced amplifier.

- (a) 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, Z_0 , and the interconnections between the main components are ideal.

[10]

- (b) For the topology in 5(a), if the working single-ended amplifiers have a forward voltage wave transmission coefficient of $S_{21} = |10|\angle 35^\circ$, 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 in 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]

6.

- (a) Describe a scalar network analyser and draw the simplified block diagram for a vector network analyser (VNA), clearly identifying all blocks. Explain how transmission measurements are performed with the VNA and list some of the advantages and disadvantages of both instruments.

[8]

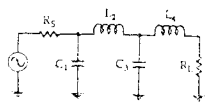
- (b) Compare and contrast test-fixture measurements with on-wafer probing.

[4]

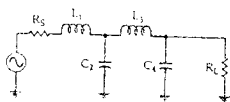
- (c) Briefly explain the basic principles by which a VNA can perform synthetic-pulse time domain reflectometry. Sketch the measured reflection response in the time domain for a slightly mismatched MMIC through-line embedded within a non-ideal test fixture. Describe how the frequency response of $|S_{11}|$ can be emphasised for the embedded MMIC. Is this 'de-embedding' process needed with on-wafer probing?

[8]

Butterworth Low-Pass
Prototype Element Values

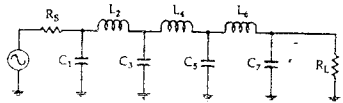


n	R_g/R_L	C_1	L_2	C_3	L_4
2	1.111	1.035	1.835		
	1.250	0.849	2.121		
	1.429	0.697	2.439		
	1.667	0.560	2.828		
	2.000	0.448	3.346		
	2.500	0.342	4.095		
	3.333	0.245	5.313		
	5.000	0.156	7.707		
	10.000	0.074	14.814		
	∞	1.414	0.707		
3	0.900	0.808	1.633	1.599	
	0.800	0.844	1.364	1.926	
	0.700	0.915	1.165	2.277	
	0.600	1.023	0.965	2.702	
	0.500	1.181	0.778	3.261	
	0.400	1.425	0.604	4.064	
	0.300	1.838	0.440	5.363	
	0.200	2.660	0.284	7.910	
	0.100	5.187	0.138	15.455	
	∞	1.500	1.333	0.500	
4	1.111	0.466	1.592	1.744	1.459
	1.250	0.368	1.695	1.511	1.811
	1.429	0.325	1.862	1.291	2.175
	1.667	0.269	2.103	1.082	2.813
	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

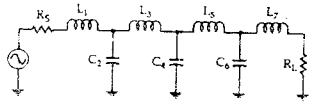


n	R_L/R_g	L_1	C_2	L_3	C_4
2					
3					
4					

Butterworth Low-Pass Prototype Element Values

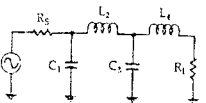


n	R_g/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	0.900	0.442	1.027	1.910	1.756	1.389		
	0.800	0.470	0.866	2.061	1.544	1.738		
	0.700	0.517	0.731	2.285	1.333	2.108		
	0.600	0.586	0.609	2.600	1.126	2.552		
	0.500	0.686	0.496	3.051	0.924	3.133		
	0.400	0.838	0.388	3.736	0.727	3.965		
	0.300	1.094	0.285	4.884	0.537	5.307		
	0.200	1.608	0.188	7.185	0.352	7.935		
	0.100	3.512	0.091	14.085	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	1.348	2.062	
	1.667	0.173	1.407	0.801	2.858	1.143	2.509	
	2.000	0.141	1.653	0.654	3.369	0.942	3.064	
	2.500	0.111	2.028	0.514	4.141	0.745	3.931	
	3.333	0.082	2.658	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	15.788	0.179	15.738	
	∞	1.533	1.789	1.553	1.202	0.758	0.259	
7	0.900	0.299	0.711	1.404	1.489	2.125	1.727	1.296
	0.800	0.322	0.608	1.517	1.278	2.334	1.548	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	2.795	0.592	4.380	0.754	3.904
	0.300	0.775	0.206	3.671	0.437	5.781	0.560	5.253
	0.200	1.145	0.135	5.427	0.287	8.528	0.369	7.908
	0.100	2.257	0.067	10.700	0.142	16.822	0.182	15.748
	∞	1.538	1.799	1.659	1.397	1.055	0.656	0.223

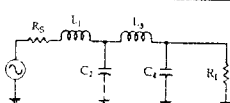


n	R_L/R_g	L_1	C_2	L_3	C_4	L_5	C_6	L_7
5								
6								
7								

Chebyshev Low-Pass Element Values
for 0.01-dB Ripple

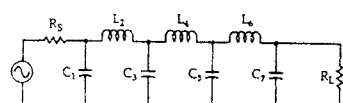


n	R_g/R_L	C_1	L_2	C_3	L_4
2	1.101	1.347	1.483		
	1.111	1.247	1.595		
	1.250	0.943	1.997		
	1.429	0.750	2.344		
	1.667	0.600	2.750		
	2.000	0.479	3.277		
	2.500	0.363	4.033		
	3.333	0.259	5.255		
	5.000	0.164	7.650		
	10.000	0.078	14.749		
	∞	1.412	0.742		
3	1.000	1.181	1.821	1.181	
	0.900	1.092	1.680	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	2.210	0.470	5.250	
	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	1.781	1.046
	1.111	0.854	1.946	1.744	1.185
	1.250	0.618	2.075	1.542	1.617
	1.429	0.495	2.279	1.334	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	3.611	0.720	3.875
	3.333	0.174	4.727	0.538	5.309
	5.000	0.112	6.910	0.352	7.613
	10.000	0.054	13.469	0.173	15.510
	∞	1.529	1.694	1.312	0.523

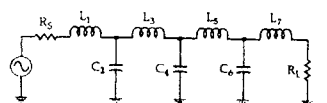


n	R_L/R_g	L_1	C_2	L_3	C_4
2					
3					
4					

Chebyshev Low-Pass Element Values for 0.01-dB Ripple



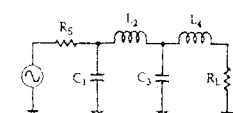
n	R_g/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	1.000	0.977	1.885	2.037	1.885	0.977		
	0.900	0.880	1.456	2.174	1.641	1.274		
	0.800	0.877	1.235	2.379	1.499	1.607		
	0.700	0.926	1.040	2.658	1.323	1.877		
	0.600	1.019	0.883	3.041	1.135	2.424		
	0.500	1.166	0.699	3.584	0.949	3.009		
	0.400	1.398	0.544	4.403	0.749	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	3.187	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	0.588	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	1.180	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	2.088	1.722	2.202	1.581	1.206
	0.800	0.811	1.150	2.282	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	0.756	3.760
	0.300	1.689	0.372	5.454	0.546	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
	∞	1.559	1.867	1.866	1.765	1.563	1.161	0.456



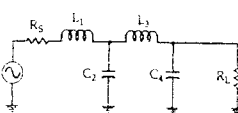
n	R_L/R_g	L_1	C_2	L_3	C_4	L_5	C_6	L_7
5								
6								
7								

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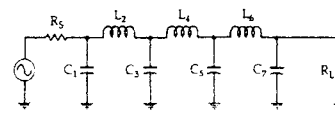
Chebyshev Low-Pass Prototype Element Values for 0.1-dB Ripple



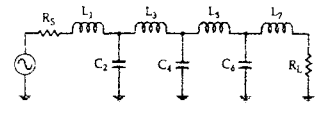
n	R_5/R_L	C_1	L_2	C_3	L_4
2	1.355	1.209	1.638		
	1.429	0.977	1.982		
	1.667	0.733	2.489		
	2.000	0.560	3.054		
	2.500	0.417	3.827		
	3.333	0.293	5.050		
	5.000	0.184	7.426		
	10.000	0.087	14.433		
	∞	1.391	0.819		
3	1.000	1.433	1.594	1.433	
	0.900	1.426	1.494	1.622	
	0.800	1.451	1.356	1.871	
	0.700	1.521	1.193	2.180	
	0.600	1.646	1.017	2.603	
	0.500	1.853	0.838	3.159	
	0.400	2.186	0.660	3.968	
	0.300	2.763	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	3.991	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	0.076	14.887	0.180	15.230
	∞	1.511	1.768	1.455	0.673



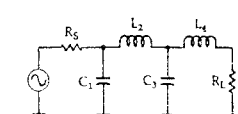
Chebyshev Low-Pass Prototype Element Values for 0.1-dB Ripple



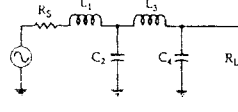
n	R_5/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	1.000	1.301	1.556	2.241	1.556	1.301		
	0.900	1.285	1.433	2.380	1.488	1.488		
	0.800	1.300	1.282	2.582	1.382	1.738		
	0.700	1.358	1.117	2.866	1.244	2.062		
	0.600	1.470	0.947	3.269	1.085	2.484		
	0.500	1.654	0.778	3.845	0.913	3.065		
	0.400	1.954	0.612	4.720	0.733	3.886		
	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	15.745		
	∞	1.581	1.807	1.766	1.417	0.651		
6	1.355	0.942	2.080	1.859	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	3.645	
	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	1.690	2.239	1.520	1.262
	0.900	1.242	1.395	2.361	1.578	2.367	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	1.099	3.384	1.081	2.444
	0.500	1.595	0.753	3.794	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	6.654	0.556	6.569	0.557	5.217
	0.200	3.428	0.286	8.937	0.369	9.770	0.372	7.990
	0.100	6.570	0.141	17.603	0.184	19.376	0.188	15.813
	∞	1.575	1.858	1.921	1.827	1.734	1.379	0.631



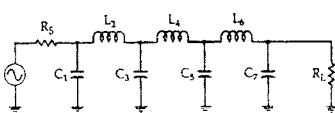
Chebyshev Low-Pass Prototype Element Values for 0.5-dB Ripple



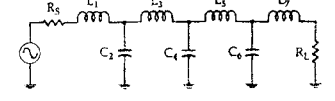
n	R_5/R_L	C_1	L_2	C_3	L_4
2	1.984	0.983	1.950		
	2.000	0.909	2.103		
	2.500	0.564	3.165		
	3.333	0.375	4.411		
	5.000	0.228	6.700		
	10.000	0.105	13.322		
	∞	1.307	0.975		
3	1.000	1.804	1.280	1.834	
	0.900	1.918	1.209	2.026	
	0.800	1.997	1.120	2.237	
	0.700	2.114	1.015	2.517	
	0.600	2.557	0.759	3.436	
	0.500	2.985	0.615	4.242	
	0.400	3.729	0.463	5.576	
	0.300	5.254	0.309	8.225	
	0.200	9.890	0.153	16.118	
	0.100	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	0.869	3.121
	3.333	0.344	5.120	0.621	4.480
	5.000	0.210	7.703	0.400	6.987
	10.000	0.098	15.352	0.194	14.262
	∞	1.436	1.889	1.521	0.913



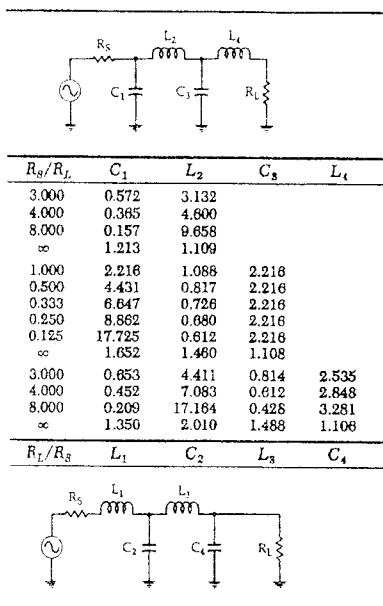
Chebyshev Low-Pass Prototype Element Values for 0.5-dB Ripple



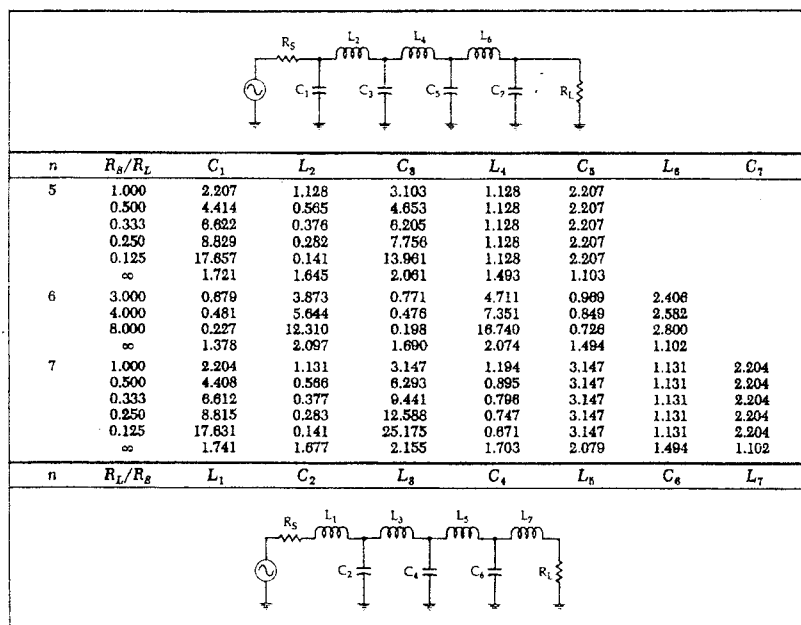
n	R_5/R_L	C_1	L_2	C_3	L_4	C_5	L_6	C_7
5	1.000	1.807	1.303	2.691	1.303	1.807		
	0.900	1.854	1.222	2.849	1.238	1.970		
	0.800	1.926	1.126	3.060	1.157	2.185		
	0.700	2.035	1.015	3.353	1.058	2.470		
	0.600	2.200	0.890	3.765	0.942	2.861		
	0.500	2.457	0.754	4.367	0.810	3.414		
	0.400	2.870	0.609	5.296	0.664	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		
	∞	1.830	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	4.481	
	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	3.070	1.215	3.107	1.155	2.168
	0.700	2.011	1.007	3.384	1.105	3.416	1.058	2.455
	0.600	2.174	0.882	3.772	0.979	3.852	0.944	2.848
	0.500	2.428	0.747	4.370	0.838	4.289	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
	∞	1.646	1.777	2.031	1.789	1.924	1.503	0.895



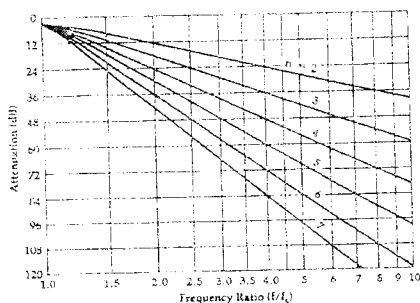
Chebyshev Low-Pass Prototype Element Values for 1.0-dB Ripple



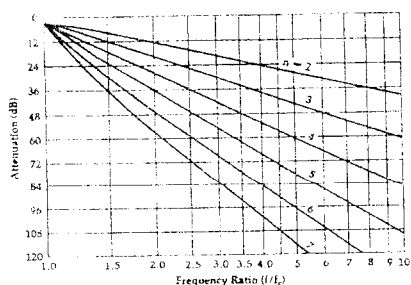
Chebyshev Low-Pass Prototype Element Values for 1.0-dB Ripple



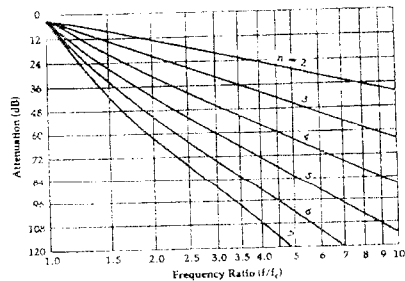
Filter tables



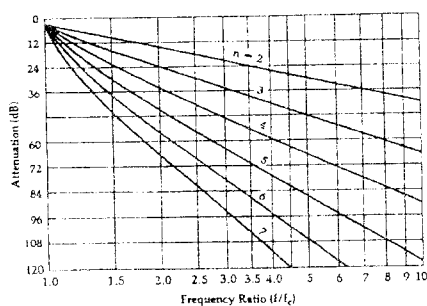
Attenuation characteristics for Butterworth filters.



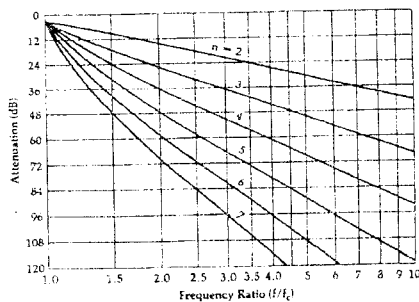
Attenuation characteristics for a Chebyshev filter with 0.01-dB ripple.



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.